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ECOLOGICAL SUBSECTIONS OF NOATAK NATIONAL PRESERVE

LANDSCAPE-LEVEL MAPPING OF ECOLOGICAL UNITS FOR THE NOATAK NATIONAL PRESERVE, ALASKA

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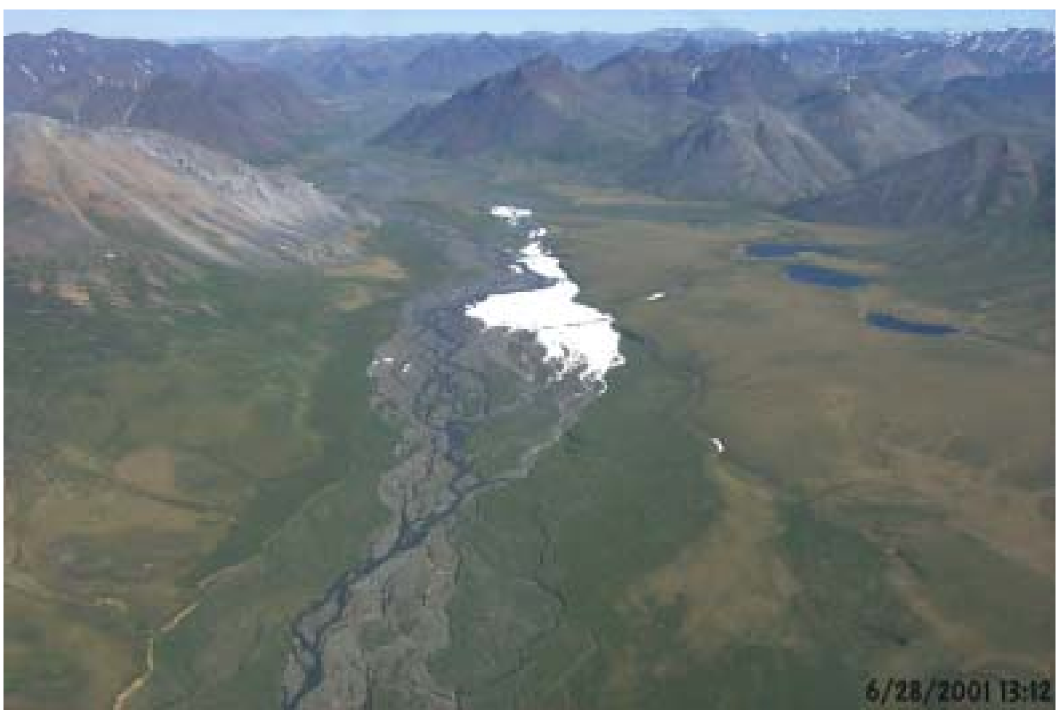

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FINAL REPORT

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INTRODUCTION

An ecological land classification is essential to evaluating land resources and refining management strategies for specific areas. More specifically, a landscape-level stratification can be used to more efficiently allocate inventory and monitoring efforts, to improve land cover classifications developed from remote sensing, to partition ecological information for analysis of ecological relationships and development of predictive models, and to improve recommendations for ecological restoration. Accordingly, the National Park Service (NPS) has decided to use landscape-level maps as the basis for stratifying their biological inventories to ensure that their field sampling is distributed appropriately across the range of environmental gradients.

An ecological land classification involves the organization of ecosystem components within a hierarchical framework of spatial and temporal scales (Rowe 1961, Wiken and Ironside 1977, O'Neil et al., 1986, ECOMAP 1993, Klijn and Udo de Haes 1994, Bailey 1996). Smaller-scale features, such as vegetation, are nested within larger-scale components, such as climate, physiography, and geology. Climatic factors, particularly temperature and precipitation, typically account for the majority of global variation in ecosystem structure and function (Walter 1979). Physiography (the distribution of broad-scale landforms with characteristic substrate types, surface shapes, and relief patterns) controls the spatial arrangement and rate of geomorphic processes because topography affects flows of material and energy (Swanson et al. 1988, Bailey 1996). Geology is important at the landscape scale because bedrock structure and chemistry affect weathering rates, surface morphology, and nutrient availability (Jenny 1941, Bailey 1996). These large-scale "state" factors (climate, physiography, geology), therefore, can be used as differentiating criteria for delineating sections (physiographic regions with similar geology and regional climate) and subsections (more narrowly defined geology with repeating associations of geomorphic units)(ECOMAP, 1993).

NPS in Alaska currently is undertaking landscape-level mapping at the subsection level of the National Hierarchical Framework (ECOMAP 1993) for all its parks in Alaska. Landscape- level maps already have been produced for the Yukon-Charley Rivers (Swanson 1999), Katmai (Shepard 2000), Bering Land Bridge (Jorgenson 2001), Kobuk (Swanson 2000, 2001a), Cape Krusenstern (Swanson 2001b), and Wrangell St. Elias (Swanson 2001c) park units. Outside the park system, similar landscape-level mapping has been done in Alaska for the central arctic coastal plain (Jorgenson et al. 1997), Fort Wainwright (Jorgenson et al. 1999), Fort Greely (Jorgenson et al. 2000), and a small portion of the Yukon-Kuskokwim Delta (Jorgenson 2000).

The Noatak River and its watershed extend from the Kotzebue Sound through the western portion of the Brooks Range (Figure 1). Because of its complex geology and variety of climatic and terrain conditions, the Noatak River watershed includes a wider diversity of ecosystems than does any other drainage of comparable size in the Arctic region. To protect ecosystems within the Noatak watershed, this large area (2.6 million hectare, 6.6 million acres) was established as a Biosphere Reserve in 1976, a National Monument in 1978, and a National Preserve in 1980. Because of the Preserve's large size and its remoteness, ecosystems in the area remain poorly studied. Most scientific studies in the area have focused on geology (Smith 1913, 1930, Mull 1982, Curtis et al. 1984, Mayfield et al. 1984, 1987, Karl et al. 1989, Mull 1989, Moore et al., 1994, Hamilton 1984a, 2001), and have provided a strong foundation for differentiating landscape units. In contrast, ecological studies have been few (Irving 1954, Dean 1964, Dean and Chesemore 1974, Young 1974a, O'Brien 1975, Douglas 1984, Major and Dale 1985, Craighead et al. 1988, Anderson et al. 1994, Binkley et al. 1997) and usually limited to a few easily accessible locations.

This paper presents the results of the mapping of landscape units at the section and subsection levels for the Noatak National Preserve (hereafter referred to as the Preserve). Specific objectives of this study were to: 1) compile existing information to characterize differences in landscape patterns and processes across the study area, 2) classify landscape units using standardized differentiating criteria, 3) map ecological units at the section and subsection levels, 4) conduct a field reconnaissance to evaluate the preliminary map and obtain photographs of each unit, 5) develop representative toposequences within selected subsections to illustrate the diverse relationships among landscape components, and 6) compare the distribution of land cover classes among subsections to evaluate how well the subsection map partitions ecological characteristics.

METHODS

DATA COMPILATION AND GEOREFERENCING

Data compilation involved reviewing existing field studies for relevant information on the characteristics of the various landscape components; compiling information on the distribution of the various components from hard copy maps; and integrating digital-map data into a georeferenced GIS database. While the data compilation focused on collecting information about topography (DEM), geology (bedrock and surficial geology), and hydrology (waterbodies and drainage networks), detailed information on soil-vegetation relationships also was included. The regional information on topography, geology, and hydrology was essential for classification and boundary delineation. Information from localized field studies was useful for evaluating how well the ecological units partitioned differences in soils and vegetation among units and for developing representative toposequences that illustrate differences among map units. Soil profiles were adapted from field descriptions by Ugolini and Walters (1974).

The literature review incorporated information on a diverse set of landscape components, including climate, tectonics and physiography, bedrock geology, geomorphology (surficial geology and periglacial processes), soils, vegetation, and paleoecology. Relevant information about each landscape component was extracted from the literature and entered into a spreadsheet database. The database included information on subsection location, landscape component (e.g., geology, soils, vegetation), class (e.g., limestone, Pergelic Cryaquept, sedge-Dryas tundra), position on landscape or relationship to other component (e.g., well-drained soil on upper slope), author, page number, and notations of other pertinent facts. Nomenclature for classes of the various landscape components followed names used by the individual authors for geology; the engineering geology mapping classification system for geomorphic units (ADGGS 1983); the U.S. soil classification system used at the time of each study for soils; and the Alaska Vegetation Classification (Viereck et al. 1992) for vegetation types. The database was used to develop descriptions of the various subsections by sorting information by subsection and landscape component.

Geologic information was obtained from studies by Beikman et al. (1980), USGS (1978, 1984), Mull (1982), Nelson and Nelson (1982), Nilsen and Moore (1982), ADGGS (1982), Mayfield et al. (1983), Mayfield et al. (1984), Curtis et al. (1984), Ellersieck et al. (1984), Boak et al. (1987), Dumoulin and Harris (1987), Mayfield et al. (1987), Mull (1989), Karl et al. (1989), ADGGS (1993), Mayfield et al. (1994), Moore et al. (1994), Mull and Werdon (1994), Kelley and Brosgé, and Mull (2000). Geomorphic information was obtained from Ugolini and Walters (1974), Scott (1977), Cannon (1977), Racine et al. (1983), Hamilton (1984a), Hamilton (1984b), Hamilton and Van Etten (1984), Binkley et al. (1995), Hamilton et al. (1987), Barnes (1987), Hamilton (1994), Elias et al. (1999), and Hamilton (2001). Soils information was obtained from MacNamara (1965), Ugolini and Walters (1974), Ugolini (1975), and Binkley et al. (1997). Vegetation information was obtained from Hanson (1953), Shelter (1964), Young (1974b, 1974c), Racine et al. (1987), Becia (1987), Craighead et al. (1988). Paleoecology information was obtained from Matthews (1974), Anderson (1988), Anderson et al. (1994), Anderson and Brubaker (1994), and Hamilton and Brigham-Grette (1991). The study sites from which the data were obtained were georeferenced by subsection in the database to facilitate access of information geographically. The numbers of observations, summarized by author and by landscape component, are provided in Appendix Table 1.

Most digital map data were provided by the NPS in GIS databases on CD-ROM. The databases included data at various scales and from a variety of sources including: an ecoregion map of Alaska (1:2.5 million scale, Nowacki et al., in press), digital elevation models developed from 1:250,000 scale USGS quadrangles, digital raster graphics of the USGS quadrangle maps (1:250,000 and 1:63,360), hydrography from USGS maps (1:63,360 scale), park, preserve, and wilderness boundaries (1:63,360 scale), and bedrock geology (1:2,500,000 scale, Beikman et al. 1980). Finally, the digital land cover map of the Preserve (Markon and Wesser 1998) was used after development of the subsection map to evaluate how well the units partitioned land cover classes. We digitized the geological map of northern Alaska by Moore et al. (1994) to provide a generalized regional view of the geology of the area.

CLASSIFICATION

While every map unit is unique, differentiation of landscape-level units requires explicit definition of the criteria used, in order to improve the objectivity of the classification and delineation and to facilitate consensus among users. Following the ECOMAP (1993) framework, sections were defined as physiographic units with similar geology and regional climate that have repeating associations of a limited set of closely related geomorphic deposits. Subsections provide further partitioning of geomorphic or lithologic variability, such as differentiating between alkaline carbonate rocks and acidic granite. To reduce geologic complexity and to deal with the high level of interspersion of rock types, bedrock types were aggregated into groups that have similar effects on soil development (Appendix Table 2). Floodplains were given special consideration and were mapped as “detailed” subsections; these units were lumped with the adjacent subsection at the subsection level.

To ensure consistency in NPS’s statewide effort, mapping investigators for other park units convened a workshop in Anchorage on 26 Sept. 2000 to develop a consensus on mapping criteria (Page Spencer, pers. comm.). At this meeting, consensus was developed to differentiate coastal (salt-affected) ecosystems and floodplain ecosystems, but not to differentiate alpine ecosystems. Alpine ecosystems present difficulties because they are part of a continuous toposequence, are difficult to define in arctic environments, and are highly patchy and disjunct on mountain tops. This distribution pattern is inconsistent with the objective of creating larger regions with a repeating assemblage of ecological conditions.

MAPPING

To provide a common base map for co-registration of map information and boundary delineation, we used a georectified mosaic of six Landsat TM images produced by Earth Satellite Corporation for their land-cover mapping project for the Noatak. During mapping, 1:63,000 scale, color-infrared, aerial photography occasionally was used to better evaluate topographic and geomorphic differences among units.

Boundaries were delineated initially on hard copy prints (1:250,000 scale) of the Landsat TM image. The maps were digitized and rectified to the image using a series of ground control points. After initial digitizing, lines were revised by on-screen digitizing over the backdrop of the Landsat TM image. While map layers representing data on topography (USGS DEM) and geology (Moore et al. 1994) were referred to during mapping, the terrain characteristics evident on the Landsat Image provided the primary control for boundary delineation. Mapping extended beyond the park boundaries where necessary to close polygons. Polygon size for the subsections was in the range of 10’s to 100’s of km², following ECOMAP (1993). The map was produced as a seamless ArcInfo coverage for the Noatak in Albers Alaska with NAD27 datum. In addition, the Noatak map was joined with the landscaping mapping done for the Kobuk and Cape Krusenstern park units. Attributes included for each polygon included park_code (e.g., NOAT), section (name), subsection (name), subseccode (subsection code), Det_SS (detailed subsection name), Det_sscode (detalied subsection code), physiograp (physiography), and lithology.

FIELD RECONNAISSANCE

A field reconnaissance was conducted on 27–28 August 2001 to familiarize the lead author with the landscape, to acquire large-scale photography of subsections for reference and presentation, and to evaluate preliminary concepts of landscape units and landscape relationships. Oblique aerial photography was obtained for all subsections (Appendix 3). Based on observations from the field reconnaissance, the preliminary map was revised by combining several subsections that had similar characteristics. In addition, individual floodplain units within each section, which initially were mapped separately, were combined as a single disjunct detailed subsection.

RESULTS AND DISCUSSION

LITERATURE REVIEW AND SYNTHESIS OF FACTORS AFFECTING LANDSCAPE EVOLUTION

The structure and function of ecosystems are regulated largely along gradients of energy, moisture, nutrients, and disturbance. These gradients are affected by climate, tectonic effects on physiography, and parent material as controlled by bedrock geology and geomorpholoy (Swanson et al. 1988, ECOMAP 1993, Bailey 1996). Thus, these large-scale ecosystem components can be viewed as state factors that affect ecological organization (Jenny 1941, Van Cleve et al. 1990, Vitousek 1994, Bailey 1996). Information on the various landscape components compiled from literature relevant to the Noatak are synthesized below, to help evaluate their importance in controlling the ecological patterns evident in the study area.

CLIMATE

Climate is a dominant factor affecting ecosystem distribution (Walters 1979). Long-term weather stations surrounding the Preserve reveal strong gradients in temperature and precipitation (Figure 2). Mean annual air temperature ranged from –5.8°C at Kotzebue in the south to –11.8°C at Umiat in the north, and from –5.8°C at Kobuk in the east to –8.1°C at Cape Lisburne in the west (WRCC 2001). Mean annual precipitation ranged from 241 mm at Kotzebue (south) to 139 mm at Umiat (north), and from 424 mm at Kobuk (east) to 288 mm at Cape Lisburne (west). Note, however, that problems with measuring blowing snow can lead to underestimation of precipitation in the arctic. All stations follow similar seasonal patterns: summers are short (June through August), winters are long, and most of the precipitation falls during July, August, and September. In addition, there is an elevational gradient in temperature, with cooler summers and generally warmer and windier winters at higher elevations, the latter due to pooling of cold air in valleys. Hammond and Yarie (1996) estimate that growing season temperatures at high elevations in the western Brooks Range average 2 to 3°C cooler than adjacent valley bottoms.

These strong climatic gradients have resulted in a wide range of ecological responses evident on the Landsat imagery used for mapping landscape units. Most of the Preserve is in the polar domain, while some portions are included in the boreal domain (Nowacki et al. *in press*). Because of low summer temperatures, vegetation over most of the area (polar domain), is dominated by graminoids, low and dwarf shrubs, mosses, and lichens. At low elevations in the Noatak Valley, (boreal domain), relatively high summer temperatures (12–13°C July mean) allow the northwesternmost trees in North America to grow in and near the Preserve. At higher elevations summer temperatures are lower and winds are stronger; as a result alpine areas frequently are barren or support only a sparse cover of lichens, mosses, and a few vascular species.

The mountains contribute to these gradients by impeding movement of large-scale air masses. The Baird Mountains appear to provide a barrier to movement of moist maritime air masses, causing precipitation to be 3 times higher on the southern slopes of the Baird Mountains (Kobuk measurements), than on the north slope of the Delong Mountains (Umiat measurements). Consequently, Spruce forest and tall alder and willow scrubland are much more prevalent in the southern Baird Mountains than in the northern Delong Mountains, presumably in response to the higher temperatures and precipitation. These gradients provided a strong basis for differentiating the southern and northern portions of mountain ranges at the section level.

Climatic conditions also have varied considerably over time. Stable isotope analysis of ice cores from Greenland and Antarctica reveal numerous large, rapid shifts in climate during the Pleistocene (Bradley 1999). These changes have resulted in multiple episodes of glaciation, associated loess deposition, and sea- level fluctuations, (Hopkins 1982), and have been documented by numerous geomorphic and paleoecological studies in the Bering Land Bridge area (Smith 1933, Matthews 1974, McColloch and Hopkins 1966, Hopkins 1967, Hopkins 1982, Hamilton and Brigham-Grette 1991, Mann and Hamilton 1995).

Fossil insects and pollen (Elias et al. 1999) indicate that during the last interglacial period (about 130,000 years ago), the climate in the Noatak Valley was similar to or slightly warmer than it is today. This interglacial was followed by a prolonged period of lower temperatures, when the vegetation was dominated by herbaceous plants. About 13,000–14,000 years ago the climate warmed, probably to conditions similar to those at present, allowing colonization of the Noatak Valley by shrubs (and locally trees) over the next few thousand years (Anderson 1988, Eisner and Colinvaux 1992, Anderson and Brubaker 1994). On the basis of beetle fossils assemblages, Elias et al. (1999) estimated that mean summer temperatures were ~2°C below and above current temperatures during glacial and interglacial periods respectively. White spruce remains, ice-wedge casts, and buried soils indicate that the climate in northwestern Alaska 8,300–10,000 years ago was warmer than at present (McColloch and Hopkins 1966).

More recently, historical records and analyses of proxy indicators (biological or physical materials that change in response to temperature) indicate that mean annual temperatures were substantially (~1°C) lower during the Little Ice age (ending around 1850) than at present, and that temperatures during the last decade (1990–2000) were the warmest in the last 400 years (Overpeck et al. 1997). This recent warming has enhanced tree growth in the Noatak Valley and allowed some expansion of spruce forest onto the tundra (Suarez et al. 1999). Future temperature increases expected as a result of global warming likely will further lead to further expansion of the forest, but the change is likely to be very slow because of the topographic barrier presented by the Brooks Range (Rupp et al. 2001).

TECTONIC SETTING AND PHYSIOGRAPHY

The Noatak National Preserve occupies a broad basin and surrounding mountains of the Brooks Range (Figure 3). The uplifting that produced the Brooks Range probably began in the mid-Jurassic and was active into the Cretaceous within the Preserve (Moore et al. 1994). This uplifting occurred when a thick piece of the earth's crust that now composes most of the Brooks Range, known as the Arctic Alaska terrane, collided with and then fused with other terranes to the south (Mull 1982, Box 1985, Mayfield et al. 1983, Karl and Long 1990, Moore 1992). The quiet-water, marine sedimentary rocks of the Arctic Alaska terrane were initially forced southward (subducted) beneath a section of oceanic crust known as the Angayucham terrane, then uplifted and eroded. As a result, bedrock in the northern part of the Preserve consists mostly of sedimentary rock, including a substantial amount of carbonate rock. In the southern part of the Preserve the bedrock is mainly metamorphic, due to heating and compression during subduction. Isolated bodies of mafic and ultramafic rocks (rocks high in magnesium and iron) are remnant pieces of the Angayucham terrane overlying the Arctic Alaska terrane. The Delong and Baird Mountains formed by this uplift are separated by the Noatak River, which flows through most of its length in an elongate basin formed in the Cenozoic after most mountain-building in this region ceased. This basin is rather shallow, and its Tertiary and Pleistocene fill is mostly less than 1 km thick (Barnes 1987, Kirschner 1994).

These tectonic forces and the resulting physiography of the Noatak Valley have exerted strong influences on ecosystem distribution and successional development through their effects on regional climate (Hammon and Yarie 1996, Van Cleve 1991), microclimate and drainage (Bailey 1996), and plant migration and survival (Suarez et al. 1999, Rupp et al. 2001). In addition, lower temperatures at higher elevations create conditions for glacier expansion into low-lying areas (Péwé 1975), resulting in substantial alteration of surficial materials that form the substrate for plant growth.

BEDROCK GEOLOGY

Bedrock is exposed on mountains and hilltops throughout the Preserve. The lithology in the Alaskan Arctic terrane, which covers most of the Preserve (Figure 4), is dominated by carbonate and noncarbonate sedimentary and metasedimentary rocks. Isolated masses of the Angayucham terrane, oceanic crust thrust over these sedimentary rocks, consist of mafic and ultramafic igneous rocks (Nelson and Nelson 1982, Curtis et al. 1984, Ellersieck et al. 1984, Mayfield et al. 1984, Karl et al. 1989, Moore et al. 1994). These different rock types have strong influences on soils and the resulting vegetation, and thus were used to differentiate ecological subsections in this study. Some of the principal differences among carbonate and noncarbonate sedimentary and metamorphic rocks, and mafic-ultramafic rocks, and their influence on soil formation, are described below. Felsic intrusive rocks (granitic rocks) are rare in the area.

Carbonate or calcareous rocks, such as limestone, dolostone, marble, and calcareous schists are common in the Baird and Delong Mountains (Dumoulin and Harris 1987, Moore et al. 1994). The relatively high pH and abundance of calcium in the alkaline soils formed by these rocks result in reduced availability of phosporus and poor absorption and utilization of phosphorus by plants (Bohn et al. 1985). These nutrient availability problems may explain the lower plant cover apparent on satellite imagery for carbonate rock regions in the Preserve. Alkaline soils also tend to be rich in humus, are often associated with more active cryoturbation, and tend to have deeper active layers (Ping et al. 1998).

Noncarbonate sedimentary (mostly shale, chert, sandstone, and conglomerate) and metamorphic (mostly schist) rocks are the most common rock types throughout the Brooks Range and the Preserve (Moore et al. 1994, Brosgé 1983). Topography is generally gentler on shales than other rock types in the Preserve. Because of reduced carbonate and calcium concentrations in the soil, the soils tend to be strongly acidic. Vegetation cover is distinctly greater on these rocks than either carbonate sedimentary rocks or ultramafic igneous rocks.

Mafic and ultramafic igneous rocks occur in several large masses in the preserve, mostly in the Delong Mountains (Nelson and Nelson 1982, Boak et al. 1987, Moore et al. 1994). These rocks consist of basalt, gabbro, and ultramafic rocks (e.g., peridotite, pyroxenite) that originated as oceanic crust before thrusting over the sedimentary rocks of the underlying Alaskan Arctic terrain. Ultramafic rocks are rich in iron and magnesium and in more southerly regions have unique soils and vegetation (Shacklette 1966, Alexander et al. 1994). Chemical analyses of dunite from Siniktanneyak Mountain in the Preserve also revealed high levels of trace metals, including chromium, nickel, and cobalt (Nelson and Nelson). Observations by Young (1974) indicate that the floristics in this area are unusual and include some rare and endemic species. Satellite imagery indicates that regions of mafic and ultramafic rocks in the Preserve generally are higher, more rugged, and support less vegetation than regions of noncarbonate sedimentary rocks.

Within the Preserve, vegetation composition varies greatly among areas with differing bedrock types, due to differences in soil pH and potential phytotoxic effects of soluble metals (described above). Acidic soils, typically associated with noncarbonate sedimentary and metamorphic rocks, usually are dominated by acid tolerant plants such as *Andromeda polifolia, Betula nana, Dryas octopetala, Empetrum nigrum, Eriophorum vaginatum, Ledum palustre, Rubus chamaemorus*, *Salix pulchra, Sphagnum* spp., and *Vaccinium uliginosum* (Hanson 1953, Young 1974, Walker et al. 1994). In contrast, common plants on alkaline soils typically include *Dryas integrifolia, Equisetum scirpoides, Lupinus arcticus, Parrya nudicaulis, Salix arctica, S. lanata,* and *S. reticulata* (Young 1974, Walker et al. 1994). Little is known about floristics on mafic and ultramafic rocks, although Young (1974) noted a number of rare species on ultramafic rocks near Feniak Lake, and Shacklette (1966) noted unusual community composition on greenstone near Eagle, Alaska.

GEOMORPHOLOGY

The geomorphology of the Noatak National Preserve was strongly affected by Pleistocene glaciations. Glaciers extended into the Noatak Valley from source areas in the surrounding mountains during the Pleistocene; they covered the entire Noatak Valley in early and middle Pleistocene time, but did not cover the valley entirely during the latest (Wisconsin) glacial period (Smith 1912, Péwé 1975, Hamilton 1994, Hamilton, 2001). Glacial moraines deposited in pre-Wisconsin glaciations have been modified greatly by subsequent thermokarst and gelifluction, so that the moraine morphology now is indistinct. Moraines deposited in Late Wisconsin time are still identifiable as lobe-shaped bodies; they have undulating topography and kettle depressions with lakes (Figure 4).

Late Pleistocene glaciers blocked the Noatak River and repeatedly impounded a large lake (Figure 4) known as glacial Lake Noatak (Hamilton and Van Etten 1984, Barnes 1987, Hamilton 2001). Sediments that were deposited in the lake are mostly fine-grained (silt and clay) but contain many ice-rafted stones (Hamilton, 2001); they cover nearly level to gently undulating lowlands in the upper Noatak River valley (Hamilton 1984a, 1984b).

Eolian activity during dry, glacial periods deposited thick beds of eolian silt (loess) over much of the northern Seward Peninsula (Mathews 1974, Hopkins 1982), and both loess and dune sand in the Kobuk Valley. Eolian deposits in the Noatak Valley are much more limited in extent, due to the occupation of the lowlands by glaciers and lakes (Hamilton 1984a, 1984b). Thick loess deposits probably are limited to gentle slopes above the shoreline of glacial Lake Noatak, and lowlands in the southwestern part of the Preserve, beyond the late Pleistocene glacial limit.

The long, gentle slopes of the hills and low mountains in the Preserve probably were formed, and continue to be modified, by gelifluction. This is the movement of saturated soil material downslope over permafrost (Washburn 1973). Gelifluction lobes are visible on many rather steep, vegetated mountain slopes in the Preserve.

Alluvial processes in narrow mountain and broad lowland valleys in the Preserve have created a dynamic landscape characterized by active erosion and deposition. Channel migration erodes and recycles surficial deposits, while deposition follows a predictable sequence from gravelly deposits in active channels, to sandy active floodplains adjacent to the active channel, to peat-covered loamy soils on inactive floodplains (Ugolini and Walters 1974, Binkley et al. 1997, Jorgenson et al. 1998). During this sequence, ice-rich permafrost aggrades in the silty cover alluvium and greatly modifies the surface with ice-wedge polygons. In higher gradient streams in the mountains, bedrock control and heavy bedload result in confined headwaters and gravelly braided floodplains. On lower gradient streams in the lowlands, sandy deposits with meandering morphology are common. The floodplains provide connectivity between regions, because water is a conduit for the movement of sediments and nutrients, as well as fish, invertebrates, and plant materials.

Permafrost distribution is nearly continuous in the Preserve because of low air temperatures (Brown et al. 1997). Permafrost in fine-grained sediments in the lowlands generally is more ice-rich than in upland areas underlain by bedrock. Most of the Noatak Valley is underlain by relatively young (Late Pleistocene) glacial and lacustrine sediments that are not as ice-rich as the loess and colluvium that accumulated in many unglaciated areas of Alaska during the Pleistocene (Péwé 1975). This low ice content, combined with the appreciable slope of these deposits, has limited the action of thermokarst over much of the Noatak Valley. Most lakes and ponds in the Valley appear to be oxbows or glacial kettles that have been modified by thermokarst, but owe their origin mainly to other causes. A very different set of conditions prevails in the lowlands in the southwestern part of the Preserve. These nearly level areas lie beyond the late Pleistocene glacial limit, and are characterized by ice-rich permafrost and many thaw lakes. Pingos are present in some of the thaw lake basins. These pingos are of the closed-system type, formed by refreezing of sediments in drained thaw lake basins (Mackay 1973). These lowlands also contain the greatest concentration of ice-wedge polygons in the Preserve, due to their gentle slopes and high proportion of fine-grained sediments. Elsewhere in the lowlands of the Preserve the most common form of patterned ground probably is frost boils (also known as nonsorted circles [Washburn 1973).

Permafrost also greatly affects ecosystem development by altering soil processes. First, permafrost forms an impermeable layer beneath the active layer, causing the surface soils to become saturated on low-lying areas and gentle slopes (Ford and Bedford 1987). Soil saturation, in turn, reduces soil oxygen and microbial decomposition and thereby increases organic matter accumulation (Höfle et al. 1998). Second, the impermeable layer eliminates subsurface leaching, so that solute removal is slowed down and occurs laterally. This lateral movement through the active layer creates distinct branching pattern of "water-tracks" on slopes and enhances plant growth in the drainages (Walker et al. 1989, Kane et al. 1992). Finally, freezing and thawing processes associated with permafrost contribute to cryoturbation (mixing of soil horizons) and development of patterned ground features, such as frost boils and ice-wedge polygons, which provide a range of wet and moist microsites. These processes all alter the composition of vegetation that can grow on the cold, saturated soils.

FIRE

Although fire is not considered an important disturbance factor in tundra ecosystems due to the lack of trees (Patterson and Dennis 1981), periodic summer droughts and thunderstorms have produced numerous fires in the Preserve during the last several decades (Racine 1981, and Racine et al. 1983). Seventy-nine fires that burned a total of 1018 km^2 during 1956–1983 were detected on Landsat imagery by Racine et al. (1983). Most of these fires occurred in lowland areas adjacent to the Noatak River. While the effects of fire are variable in this landscape, they can be locally important where they increase the depth of the active layer and initiate permafrost degradation (Racine 1981).

CLASSIFICATION AND MAPPING

Landscape-level units within the Noatak National Preserve were classified within the ecoregion framework for Alaska. This framework differentiated three ecoregions that included portions of the Noatak study area: the Brooks Range, the Kobuk Ridges and Valleys, and the Kotzebue Sound Lowlands (Nowacki et al., *in press*). Based on differences in physiography and geology, the landscape classification of the Preserve resulted in the establishment of 6 sections and 57 subsections (including 4 detailed subsections for floodplains) within the Brooks Range, 2 sections and 7 subsections (including 1 detailed subsection) within the Kobuk Ridges and Valleys, and 2 sections and 2 subsections within the Kotzebue Sound Lowlands for the Preserve (Table 1). Twelve additional subsections were mapped adjacent to the preserve boundaries to complete sections that extended outside the preserve (Appendix Table 4).

Mapping of subsections reveals a wide diversity of ecosystems within the Preserve, ranging from salt-affected coastal areas in the Noatak Delta, to floodplains extending to the headwaters of the Upper Noatak Floodplain, to exposed bedrock in rugged mountain areas with very different bedrock chemistries (Figure 5). The subsections cross a steep gradient of climatic conditions that results in forested slopes and floodplains along the southern margin to dwarf scrub along the northern margin. Aggregation of the subsections into broader sections, based principally on climatic and physiographic conditions, greatly simplifies the map patterns (Figure 6). The subsections can also be aggregated based on their geologic characteristics to produce a simplified bedrock and surficial geology map that can provide a simplified basis for stratification of monitoring and inventory work (Figure 7). The units also were aggregated by their physiographic characteristics (Figure 8).

ECOLOGICAL UNIT DESCRIPTIONS

AGASHASHOK MOUNTAINS (AAM)

Rugged mountains (elevation range of 182–1232 m) along the western crest of the Baird Northern Mountains comprised of metalimestone and marble. Rocky ridges and outcrops have excessively drained, poorly developed alkaline soils that are mostly barren, or occasionally support *Dryas*-lichen and sedge-*Dryas* tundra. Colluvial slopes have saturated, loamy organic-rich soils that are highly turbated from frost action and gelifluction. Sedge-*Dryas* tundra predominates. Drainages are gravelly and partially vegetated. Permafrost is continuous, with low (<10%) ice content. Photo TJ01J843, 28 June 2001.

AKIAK MOUNTAINS (AKM1)

Rugged mountains (86–1233 m) in the central Baird Southern Mountains comprised mostly of schist. Ridges and upper slopes have rubble and bedrock outcrops that are mostly barren. Lower slopes have dry, rocky soils, thin organic horizons, and support shrub birch-ericaceous shrub, alder, and open spruce forest. Drainages are gravelly and partially vegetated. Permafrost is continuous, with low ice content. [unit in KOVA, no photo].

AKLUMAYUAK FOOTHILLS (AKH)

Rounded foothills (167–1094 m) in the central Baird Northern Mountains comprised of shale, conglomerate, sandstone, and siliceous phyllite. The ridges have rubbly fell-fields (frost-shattered rocks), while lower slopes are mantled with colluvium. Rocky ridges have excessively drained, poorly developed acidic soils that support *Dryas*-lichen tundra or are barren. Colluvial slopes have saturated, loamy soils with thick organic horizons that are highly turbated from frost action and gelifluction. Vegetation is dominated by dwarf birch-ericaceous shrub, willow scrub, and shrub-tussock tundra. Drainages and headwater floodplains support willow scrub. Photo TJ01J691, 27 June 2001.

AKLUMAYUAK GLACIATED UPLANDS (AKU)

Gently rolling uplands (244–675 m) in the upper Noatak Basin covered with glacial drift associated with the Itkillik glaciation. Gentle slopes have wet soils with thin to thick organic horizons, abundant frost boils, and vegetation dominated by tussock tundra. Gravelly morainal ridges have excessively drained soils that support *Dryas* tundra and shrub birch-ericaceous shrub. Permafrost is continuous and has a low ice content. Photo TJ01D13, 27 June 2001.

AMBLER FOOTHILLS (OUTSIDE OF PRESERVE) (AMH)

Rounded mountains (58–820 m) at the southern edge of the Southern Schwatka Mountains, comprised of phyllite, metasandstone, and basalt. Ridge crests have rocky soils with sparse vegetation or low shrubs. Slopes are covered with stoney loamy colluvium. Soils on upper slopes have a thin organic surface layer, support alder or willow scrub and probably have permafrost deep in the profile. Lower slopes that have wetter soils with permafrost and a thicker organic surface layer, and support spruce forest or woodland. [no photos].

AMBLER MOUNTAINS (OUTSIDE OF PRESERVE) (AMM)

Rugged mountains (56–1346 m) in the Southern Schwatka Mountains comprised of schist and lesser amounts of other metasedimentary and metavolcanic rocks. The highest ridges have steep slopes with barren exposed rock or rock rubble. Below these ridges, slopes are probably covered with stoney colluvium, with more loamy matrix in downslope positions. On upper slopes soils probably have permafrost rather deep in the profile and a thin organic surface layer, with low shrub vegetation. Lower slopes that have wetter soils with permafrost and a thicker organic surface layer, and support spruce forest or woodland. [no photos].

ANAKTOK MOUNTAINS (ATM1)

Rugged mountains (351–984 m) in the central Baird Northern Mountains formed from marble, with lesser amounts of carbonaceous quartzite and quartz conglomerate. Rocky ridges and outcrops have excessively drained, poorly developed alkaline soils that support *Dryas*-lichen and sedge-*Dryas* tundra, or occasionally are barren. Colluvium on lower slopes and saddles has saturated, loamy soils with thick organic horizons that frequently are highly turbated from frost action and gelifluction. Vegetation is dominated by sedge-*Dryas* tundra. Drainages have saturated, loamy soils with thick organic horizons and support closed low willow scrub. Photo TJ01J627, 27 June 2001.

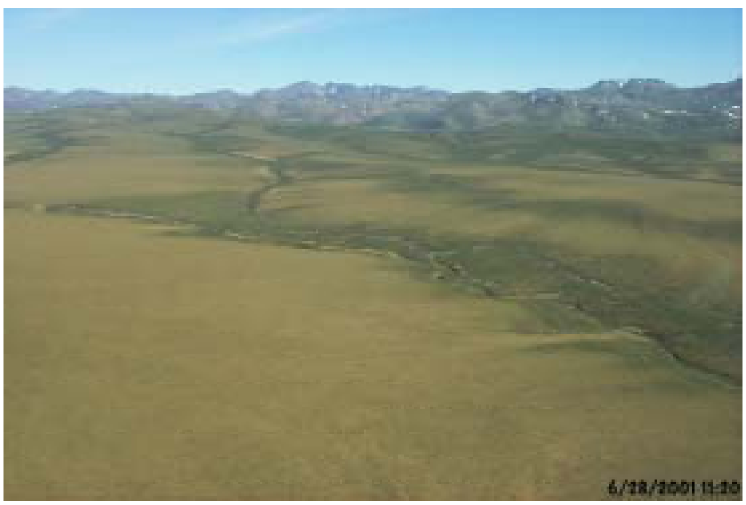
ANGAYUK-AQSRAQ MOUNTAINS (AYM1)

Rugged mountains (279–1417 m) in the central Baird Northern Mountains comprised of metasedimentary, metavolcanic, and polymetamorphic mafic rocks, gabbro, and lesser amounts of granite, granodiorite, and carbonate rocks. Rocky ridges have excessively drained, poorly developed soils that are mostly barren. Lower colluvial slopes have wetter soils that support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Drainages support low willow scrub. Permafrost is continuous and has a low ice content. Photo TJ01J631, 27 June 2001.

ANISAK MOUNTAINS (ANM)

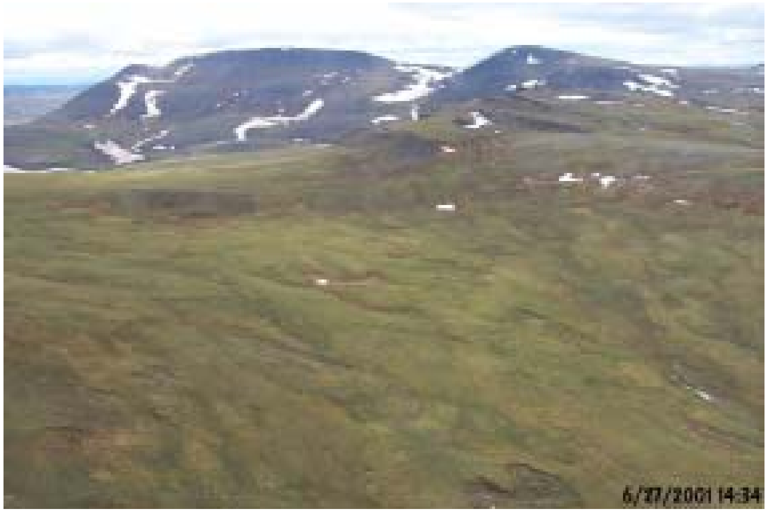
Rugged to rounded mountains (365 to1476 m) in the eastern DeLong Mountains comprised of a complex of noncarbonate and carbonate sedimentary rocks, including graywacke, mudstone, conglomerate, sandstone, shale, carbonaceous shale, chert, and limestone. Ridges and upper slopes are mostly barren, while lower colluvial slopes support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Drainages and headwater streams support low willow scrub. Permafrost is continuous and has a low ice content. Photo TJ01G09, 28 June 2001.

ANISAK UPLANDS (ANU)



Gently rolling uplands (295–631 m) in the Noatak Basin with occasional rounded hills comprised of mixed noncarbonate and carbonate sedimentary rocks. Lower areas have glaciolacustrine sediments deposited during the Itkillik glaciation. The area has extensive gentle slopes with wet, saturated soils that support tussock tundra. Ridges are uncommon and have better drained soils that support *Dryas* tundra and shrub birch-ericaceous shrub. Drainages have dwarf birch and willow scrub. Permafrost is continuous with low–moderate ice content. Photo TJ01J785, 28 June 2001.

ANIUK MOUNTAINS (AIM)



Rounded mountains (423–1227 m) in the eastern DeLong Mountains dominated by conglomerate, sandstone, and shale, but including small outcrops of basalt and limestone. Ridges and upper slopes are mostly barren, while lower colluvial slopes support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Drainages and headwater streams support willow scrub. Permafrost is continuous and has a low ice content. Photo TJ01J674, 27 June 2001.

ASIK MOUNTAIN (ASM)

Rounded, isolated ridges (70–685 m) in the western Baird Northern Mountains comprised of ultramafic and gabbroic rocks. Barren fellfields on ridges are common. The colluvial slopes support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Permafrost is continuous and has a low ice content. Photo TJ01A12, 27 June 2001.

AVAN MOUNTAINS (AVM)

Rugged mountains (193–1234 m) in the central DeLong Mountains comprised of gabbro, peridotite, pyroxenite, pegmatite, dunite, basalt, shale, and chert. Barren fellfields and talus slopes predominate and the iron-rich bedrock contributes to distinctive reddish-brown weathered rocks. The lower mountain slopes have colluvium with moist soils that support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. A few cirque lakes are present. Permafrost is continuous and has a low ice content. Photo TJ01J764, 28 June 2001.

AVINGYAK GLACIATED UPLANDS (AGU)

Gently rolling upland area (364–612 m)in the upper Noatak Basin covered with glacial drift associated with the Itkillik glaciation. Kettle lakes are common. Gentle slopes have wet soils with thin to thick organic horizons, abundant frost boils, and vegetation dominated by tussock tundra (Ugolini and Walters 1974). Gravelly morainal ridges are common and have well-drained soils that support *Dryas* tundra and shrub birch-ericaceous shrub. Lake shores and drainages support willow scrub and wet sedge meadows. Photo TJ01J792, 28 June 2001.

AVINGYAK HILLS (AGH)

Rounded hills (327–741 m) in the upper Noatak Basin with outcrops comprised of conglomerate, sandstone, shale. The ridges and upper slopes are mostly barren, with some *Dryas* tundra. Lower colluvial slopes have moist, organic-rich soils that support shrub birch-ericaceous and willow scrub. Flats and gentle slopes have shrub-tussock tundra. Lake shores and drainages support willow scrub and wet sedge meadows. Permafrost is continuous and has a low ice content. Photo TJ01D06, 27 June 2001.

BASTILLE MOUNTAINS (BAM)

Rugged mountains (348–1345 m) in the central DeLong Mountains comprised of a complex of mafic volcanic, noncarbonate and carbonate sedimentary rocks, including basalt and other mafic extrusives, graywacke, mudstone, conglomerate, shale, sandstone, chert, and limestone. Steep ridges and upper slopes mostly have barren talus. Colluvial slopes have moist, organic-rich soils that support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Drainages support willow scrub. Permafrost is continuous with low ice content. Photo TJ01G14, 28 June 2001.

CUTLER HILLS (CUH)

Rounded hills (299–734 m) in the upper Noatak Basin comprised of carbonate sedimentary rocks, mostly limestone. Rocky outcrops have excessively drained, alkaline soils that are mostly barren, but have some Dryas tundra. Colluvial slopes support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Permafrost is continuous and has a low ice content. Photo TJ01C06, 27 June 2001.

DELONG MOUNTAIN FLOODPLAINS (DMF)

Gently sloping (101–613 m) headwater and braided floodplains in the Delong Mountains. Barren channel gravels are extensive. The adjacent floodplain has well-drained gravelly soils with little accumulation of fine-grained cover deposits. Vegetation is dominated by low willow and dwarf birch scrub. Open cottonwood forest are common. Aufeis patches resulting from the overflow of shallow groundwater are common. Photo TJ01J806, 28 June 2001.

ELI FOOTHILLS (ELH)

Gently sloping uplands and foothills (10–553 m) in the western Baird Northern Mountains comprised of colluvium, large alluvial fans, and scattered rock outcrops. The moist to wet, organic-rich soils support shrub birch-ericaceous shrub and tussock tundra on gentle slopes, while open spruce forest occur in protected areas. Alder and willow scrub on hill slopes is common. Permafrost is continuous with low–moderate ice content. Photo TJ01H01, 28 June 2001.

ELI MOUNTAINS (ELM)

Rounded mountains (74–865 m) in the western Baird Northern Mountains comprised of limestone and marble. Barren fellfields and talus cover most of the area. Colluvial slopes have moist, organic-rich, nonacidic soils that support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Well developed drainages are lacking but usually support low willow scrub. Permafrost is continuous with low ice content. Photo TJ01A19, 27 June 2001.

ENDICOTT MOUNTAIN FLOODPLAINS (EMF)

Flat to gently sloping floodplains (473–609 m) of headwater, braided, and meandering streams in the Endicott Mountains. Barren channel gravels are extensive. The adjacent floodplain has well-drained gravelly soils with varying thicknesses of fine-grained cover deposits. Vegetation is dominated by low willow and dwarf birch scrub during early stages of floodplain development. Older floodplains with wet organic soils support wet sedge meadows. Permafrost probably is absent channels and present under the inactive floodplain. Photo TJ01J659, 27 June 2001.

IGGIRUK MOUNTAINS (IGM)

Rounded mountains and hills (273–990 m) in the central DeLong Mountains comprised of mixed carbonate and noncarbonate rocks, including limestone, carbonaceous shale, chert, sandstone, siltstone, mudstone, graywacke, shale, and conglomerate. Fellfields on ridges and upper slopes are mostly barren. Colluvial slopes have moist organic-rich soils that support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Drainages support willow scrub and wet sedge meadows. Permafrost is continuous and has a low ice content. Photo TJ01J685, 27 June 2001.

IGGIRUK GLACIATED UPLANDS (IGU)

Gently rolling uplands (185–579 m) in the upper Noatak Basin developed from glaciolacustrine deposits associated with a glacial-dammed lake during the Itkillik glaciation. Most slopes have moist, organic-rich soils that support shrub birch-ericaceous shrub and shrub-tussock tundra. Drainages support willow scrub and wet sedge meadows. Permafrost is continuous and has moderate to high ice content. Thaw lakes are common. Photo TJ01D11, 27 June 2001.

IKALUKROK MOUNTAINS (IKM)

Rounded mountains (199–981 m) in the western DeLong Mountains comprised of noncarbonate sedimentary rocks, including shale and quartzite. Fellfields on ridges are mostly barren, with Dryas tundra in more stable areas. Colluvial slopes have moist, organic-rich soils that support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Drainages have willow scrub. Permafrost is continuous with low ice content. Photo TJ01J815, 28 June 2001.

IMELYAK FOOTHILLS (IMH)

Rounded mountains (333–1184 m) in the western Baird Northern Mountains comprised of a complex of carbonate and noncarbonate sedimentary and metamorphic rock, including limestone, marble, calcareous schist, quartzite, phyllite, and conglomerate. Fellfields on ridges and upper slopes are mostly barren. Colluvial slopes have moist organic-rich soils that support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Drainages support willow scrub and wet sedge meadows. Permafrost is continuous and has a low ice content. Photo TJ01C08, 27 June 2001.

IMIKNEYAK MOUNTAINS (IMM)

Rugged mountains (207–1230 m) in the central DeLong Mountains comprised of a complex of mafic volcanics, noncarbonate and carbonate sedimentary rocks, including basalt, diabase, graywacke, mudstone, conglomerate, shale, sandstone, chert, and limestone. Fellfields on ridges and steep talus slopes are usually barren. The colluvium on upper slopes probably have moist, organic-rich soils that support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra, while lower slopes often have alder scrub. Drainages support willow scrub and wet sedge meadows. Permafrost is continuous and has a low ice content. Photo TJ01J780, 28 June 2001.

IPNAVIK MOUNTAINS (IPM)

Rugged mountains (489–1413 m) in the western Endicott Mountains comprised of noncarbonate sedimentary rocks, including conglomerate, sandstone, and shale. Ridges and upper slopes mostly have barren fellfields or *Dryas*-lichen tundra. Colluvial slopes have moist, organic-rich soils that support shrub birch-ericaceous shrub, and willow scrub. Drainages support willow scrub. Permafrost is continuous and has a low ice content. Photo TJ01J677, 27 June 2001.

KALUKTAVIK MOUNTAINS (KLM)

Rounded mountains (215–1171 m) in the central DeLong Mountains comprised of noncarbonate sedimentary rocks, including sandstone, siltstone, shale, slate, phyllite, and conglomerate. Ridges and upper slopes are mostly barren, while lower colluvial slopes support shrub birch-ericaceous shrub and willow scrub. Drainages and headwater streams support low willow scrub. Permafrost is continuous and has a low ice content. Photo TJ01F28A, 28 June 2001.

KALUKTAVIK UPLANDS (KLU)

Rounded hills and gentle slopes (115–779 m) in the central DeLong Mountains comprised of noncarbonate sedimentary rocks, including sandstone, siltstone, shale, slate, phyllite, and conglomerate. Slopes are mantled with rocky colluvium and have moist, organic-rich soils which support shrub birch-ericaceous shrub, willow and alder scrub, and shrub-tussock tundra. Permafrost is continuous and has a low ice content. Photo TJ01J703, 27 June 2001.

KAVACHURAK FOOTHILLS (KVH)

Round hills (385–1264 m) in the western Schwatka Mountains, comprised of noncarbonate sedimentary rocks including shale and conglomerate. Barren ridges are uncommon. Colluvial slopes have moist, acidic, organic-rich soils that support shrub birch-ericaceous shrub and willow scrub. Drainages support low willow scrub. Permafrost is continuous and has a low ice content. Photo TJ01J649, 27 June 2001.

KAVACHURAK GLACIATED UPLANDS (KGU)

Subdued knob and kettle topography (363–768 m) in the upper Noatak Basin derived from the Itkillik glaciation. Drainage is poorly integrated and isolated depressions are common Well-drained, gravelly soils on upper slopes and ridges support *Dryas* tundra, shrub birch-ericaceous shrub, and low willow scrub. Lower slopes and flats have wet organic-rich soils that support tussock tundra. Kettle lakes are abundant and shores support willow scrub and wet sedge meadows. Permafrost is continuous with low-moderate ice content. Photo TJ01C19, 27 June 2001.

KAVACHURAK MOUNTAINS (KVM)

Rugged mountains (344–1865 m) in the northwestern Schwatka Mountains comprised of mixed carbonate and noncarbonate rocks, including limestone, other carbonates, conglomerate, quartzite, phyllite, and shale. Most of the area is covered by barren fellfields and talus slopes. More stable slopes have *Dryas* tundra. Colluvial slopes have moist to wet, organic-rich soils that support *Dryas*-sedge tundra shrub, birch-ericaceous shrub, and willow scrub. Drainages and alluvial fans have willow scrub. Permafrost is continuous with low ice content. Photo TJ01C14, 27 June 2001.

KELLY MOUNTAINS (KEM)

Rugged mountains (198–1237 m) in the western DeLong Mountains comprised of mixed carbonate and noncarbonate sedimentary rocks, including limestone, dolomite, sandstone, shale, and chert. Extensive fellfields and talus slopes are mostly barren, although *Dryas* tundra is common in more stable areas. Upper colluvial slopes on carbonate rocks have moist, organic-rich, alkaline soils that support sedge-*Dryas* tundra, while lower slopes have more acidic soils that support shrub birch-ericaceous shrub and willow scrub. Headwater floodplains are gravelly and mostly barren. Permafrost is continuous and has a low ice content. Photo TJ01G17, 28 June 2001.

KELLY UPLANDS (KEU)

Hillslopes and valley bottoms (86–733 m) along Kelly River drainages in the western DeLong Mountains. Surficial deposits are dominated by colluvium, glacial drift, alluvial fans, braided floodplains, and headwater floodplains. Upper slopes have moderately well-drained soils that support shrub birch-ericaceous shrub and willow scrub, with spruce forest locally present on protected sites. Tussock tundra occurs on gentle toe slopes. Headwater floodplains are gravelly and mostly barren. Permafrost is continuous and has a low ice content. Photo TJ01J756, 28 June 2001.

KIANA COASTAL PLAIN (KCP)

Low-lying coastal plain (0–90 m) in the Kotzebue Sound Lowlands comprised of alluvial, lacustrine, and marine deposits extensively modified by thaw lake processes and capped with thick loess deposits. The coastal plain was formed by marine transgressions that raised sea levels 40–60 m above today's. Permafrost is ice-rich and thermokarst lakes formed from thaw of permafrost are abundant. Thaw basins have seasonally flooded, saturated, loamy to peaty soils that support wet sedge meadow tundra. Upland broad ridges have saturated, silty soils, abundant frost boils, and support tussock tundra and sedge-willow scrub. Lake shores and exposed pond bottoms with better-drained soils support closed low willow scrub and bluejoint meadows. Shallow ponds often have fresh grass marsh. Pingos occasionally develop in drained lake basins. Photo TJ01A03, 27 June 2001.

KIANA HILLS (OUTSIDE OF PRESERVE) (KIH)

Rounded hills (32–793 m) near Kotzebue Sound comprised of a complex assemblage of volcanic and metamorphic rocks, including metavolcanics, schist, and marble. Barren fellfields occur on isolated high knobs. Colluvial slopes have moderately well-drained soils that support extensive open spruce forest, and alder and willow scrub. Drainages support willow scrub. Permafrost is continuous and has a low ice content. Photo TJ01B36, 28 June 2001.

KIANA LOWLANDS (KIL)

Gentle slopes (0–320 m) at the base of the Kiana Hills, dominated by colluvial and eolian deposits. The slopes have moist to wet, organic-rich soils that support shrub birch-ericaceous shrub, low willow scrub, and shrub-tussock tundra. Open spruce forest is common on well-drained gentle ridges. Drainages support willow scrub. Permafrost is continuous and has moderate ice content; some thermokarst ponds are present. Photo TJ01A04, 28 June 2001.

KIKMIKSOT MOUNTAINS (KIM)

Rugged mountains (148–1106 m) in the western Baird Northern Mountains comprised of a complex of mafic intrusive and carbonate metamorphic rocks, including basalt, gabbro, marble, carbonate, and chert. Barren fellfields predominate. Colluvial slopes support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Open spruce forest occur in sheltered areas. Permafrost is continuous and has a low ice content. Photo TJ01J841, 28 June 2001.

KOKOLIK MOUNTAINS (KOM)

Rugged mountains (302–1173 m) in the western DeLong Mountains comprised of graywacke, mudstone, conglomerate, shale, and chert. Fellfields on ridges and talus slopes are extensive and mostly barren, with Dryas tundra in more stable areas. Colluvial slopes have moist, organic-rich soils that support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Permafrost is continuous with low ice content. Photo TJ01G23, 28 June 2001.

KUGURUROK MOUNTAINS (KUM)

Rugged to rounded mountains (175–1100 m) in the central DeLong Mountains comprised of noncarbonate sedimentary rocks, including sandstone, siltstone, shale, conglomerate, graywacke, and chert. Fellfields on ridges and talus slopes are common and mostly barren, with Dryas tundra in more stable areas. Colluvial slopes have moist, organic-rich soils that support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Permafrost is continuous with low ice content. Photo TJ01B12, 28 June 2001.

KUGURUROK UPLANDS (KUU)

Hillslopes and valley bottoms (125–621 m) along the Kugururok River drainages in the western DeLong Mountains. Surficial deposits include colluvium, glacial drift, alluvial fans, braided floodplains, and headwater floodplains. Upper slopes have well-drained soils that support shrub birch-ericaceous shrub and willow scrub. Tussock tundra occurs on gentle toe slopes. Headwater floodplains are gravelly and mostly barren. Permafrost is continuous and has a low ice content. Photo TJ01J769, 28 June 2001.

KUNYANAK MOUNTAINS (KYM)

Rugged mountains (356–1227 m) in the central Baird Northern Mountains, comprised of mixed carbonate and noncarbonate sedimentary rocks, including limestone, siliceous phyllite, sandstone, and conglomerate. Extensive fellfields and talus slopes are mostly barren, although *Dryas* tundra is common in more stable areas. Upper colluvial slopes on carbonate rocks have moist, organic-rich, alkaline soils that support sedge-*Dryas* tundra, while lower slopes have more acidic soils that support shrub birch-ericaceous shrub and willow scrub. Headwater floodplains are gravelly and mostly barren. Permafrost is continuous and has a low ice content. Photo TJ01J632, June 2001.

LOWER NOATAK FLOODPLAIN (LNF)

Flat, low-lying areas (2–100 m) along the lower Noatak River that includes the braided river, wide expanses of channel gravels, and active and inactive floodplains that are subject to frequent to occasional flooding. Exposed channel bars have gravelly to sandy, well-drained soils that support pioneering vegetation and willows (Ugolini and Walters 1974). Inactive floodplains with thick, stratified, loamy deposits support cottonwood and spruce forests. Abandoned channels have wet soils with wet sedge meadows. Permafrost probably is absent under the active channels, develops under the exposed point bars, and is common under the spruce forest. Photo TJ01D32, 27 June 2001.

LOWER NOATAK LOWLANDS (LNL)

Flat, low-lying plain (10–114 m) adjacent to the lower Noatak River, comprised of abandoned floodplains, terraces, abandoned channels and extensive thaw lakes. Abandoned floodplains and terraces have poorly drained soils with moderately thick organic horizons that support shrub tussock tundra, willow scrub and alder scrub (Ugolini and Walters 1974). Thaw basins support wet sedge meadows, and palsas developed on newly aggrading permafrost support dwarf birch-ericaceous shrub tundra. Pingos occasionally develop in drained lake basins and have well-drained soils on the sideslopes that support spruce forest and alder scrub. Permafrost is continuous and has high (>20%) ice content. Photo TJ01E05, 27 June 2001.

LOWER NOATAK MORAINE (OUT OF PRESERVE) (LNM)

Gently sloping uplands (10–235 m) in the lower Noatak lowlands formed from morainal deposits left by the Sagavanirktok glaciation. Slopes have moist to wet, organic-rich soils that support shrub birch-ericaceous shrub, willow scrub, and tussock tundra. Willow scrub in drainages is abundant. Open spruce forest occur in sheltered, south-facing slopes. Permafrost is continuous and has a low ice content. Photo TJ01J726, 27 June 2001.

MIDDLE NOATAK FLOODPLAIN (MNF)

Flat, low lying areas (86–253 m) along the central portion of the Noatak River where the narrow meandering floodplain is constrained by bedrock bluffs. The floodplain undergoes a successional sequence from barren gravel bars with early successional grasses and forbs, to alder-willow scrub in frequently flooded areas, to wet sedge tundra on inactive and abandoned floodplains. Shallow ponds in abandoned channels are common. Permafrost develops under the exposed point bars, and usually is present under the inactive floodplain. Photo TJ01J693, 27 June 2001.

MIDDLE NOATAK UPLANDS (MNU)

Gently rolling uplands (89–453 m) adjacent to the middle Noatak drainage comprised of glacial till, bedrock ridges, and alluvial terraces. The area is dominated by gentle slopes with moist to wet, organic-rich soils that support tussock tundra. Occasional boggy depressions support shrub birch-ericaceous shrub and drainages have willow scrub. Permafrost is continuous and has low-moderate ice content. Photo TJ01J694, 27 June 2001.

MISHEGUK MOUNTAINS (MIM)

Rugged ridges (254–1355 m) in the central DeLong Mountains comprised of gabbro, peridotite, pyroxenite, pegmatite, dunite, basalt, diabase, shale, and chert. Barren talus slopes predominate and the iron-rich bedrock contributes to distinctive reddish-brown weathered rocks. The lower mountain slopes have colluvium with moist soils that support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Permafrost is continuous and has a low ice content. Photo TJ01F24A, 28 June 2001.

NAKOLIK MOUNTAINS (NAM)

Rounded mountains (218–1108 m) in the central Baird Northern Mountains, comprised of calcareous phyllite, limestone, metalimestone, and marble. Barren fellfields are abundant. Upper slopes and less exposed ridges have rocky, dry to moist, alkaline soils that support *Dryas* tundra and *Dryas*-sedge tundra. Lower slopes have moist to wet, organic-rich soils that support shrub birch-ericaceous shrub and willow scrub. Headwater streams have gravelly, mostly barren floodplains. Permafrost is continuous and has a low ice content. Photo TJ01A24, 27 June 2001.

NATMOTIRAK FOOTHILLS (NTH)

Rounded hills (315–1101 m) in the central Baird Northern Mountains, comprised of mixed carbonate and non-carbonate metamorphic rocks, including calcareous schist, marble, quartzite, and phyllite. Barren fellfields are uncommon. Colluvial slopes with moist, organic-rich soils support *Dryas*-sedge tundra, shrub birch-ericaceous shrub, and willow scrub. Drainages have willow scrub. Permafrost is continuous with low ice content. Photo TJ01A31, 27 June 2001.

NATMOTIRAK MOUNTAINS (NTM)

Rounded mountains (222–1229 m) along the crest of the central Baird Northern Mountains comprised of mixed carbonate-noncarbonate metamorphic rocks including calcareous schist, marble, quartzite, and phyllite. Barren fellfields predominate. Colluvial slopes with moist, organic-rich soils support *Dryas*-sedge tundra, shrub birch-ericaceous shrub, and willow scrub. Permafrost is continuous with low ice content. Photo TJ01C01, 27 June 2001.

NIGU GLACIATED UPLANDS (NGU)

Gently rolling glaciated valley (520–962 m) in the Endicott Mountains, covered with glacial drift associated with the Walker, Itkillik, and Sagavanirktok glaciations. Kettle lakes are common. Gentle slopes have wet soils with thin to thick organic horizons, abundant frost boils and vegetation dominated by tussock tundra. Gravelly morainal ridges have excessively drained soils that support *Dryas* tundra. Shrub birch-ericaceous shrub tundra occurs on moist slopes. Lake shores and drainages support willow scrub and wet sedge meadows. Photo TJ01J660, 27 June 2001.

NIMIUKTUK HILLS (NIH)

Hills and valleys (204–733 m) in the central DeLong Mountains comprised of noncarbonate sedimentary rocks, including graywacke, mudstone, sandstone, shale, chert, and conglomerate, with minor limestone. Surficial deposits are dominated by colluvium, glacial drift, alluvial fans, braided floodplains, and headwater floodplains. Upper slopes have moderately well-drained soils that support shrub birch-ericaceous shrub and willow scrub. Tussock tundra occurs on gentle toe slopes. Headwater floodplains are gravelly and mostly barren. Permafrost is continuous and has a low ice content. Photo TJ01J782, 28 June 2001.

NOATAK BASIN FLOODPLAINS (NBF)

Flat, low-lying areas (134–496 m) along meandering rivers within the Noatak Basin. Active channel deposits are gravelly and usually barren. Soils on the adjacent floodplain range from well-drained gravelly soils to saturated loamy soils. Vegetation is dominated by low willow and dwarf birch scrub during early stages of floodplain development. Older floodplains with wet organic soils support wet sedge meadows. Permafrost develops under the exposed point bars, and usually is present under the inactive floodplain. Photo TJ01J684, 27 June 2001.

NOATAK DELTA (NOD)

Flat, low-lying delta (0–30 m) at the mouth of the Noatak River, comprised of the Noatak River, estuarine nearshore water, active channel deposits, inactive and abandoned delta floodplains, beach ridges, tidal ponds, and freshwater thaw lakes. Within the salt-affected zone, the lower mudlflats are barren or have pioneering salt-tolerant plants, the high tidal flats support salt marshes, and higher, sandier beaches support dunegrass meadows. Slightly saline, well-drained banks support crowberry tundra, dwarf willow scrub, shrub birch-ericaceous shrub, and open spruce forest. Higher, abandoned floodplains have organic-rich, wet soils that support tussock tundra. Permafrost is discontinuous under a range of aggrading and degrading conditions. Photo TJ01J735, 27 June 2001.

NOATAK GLACIATED LOWLANDS (NGL)

Gently rolling glaciated lowlands (10–281 m) along the lower Noatak River, covered with glacial drift associated with the Itkillik glaciation. Kettle lakes are common. Gentle slopes have wet soils with thin to thick organic horizons, abundant frost boils and vegetation dominated by tussock tundra. Well-drained slopes support open spruce forest. Shrub birch-ericaceous shrub tundra occurs on moist slopes and in boggy areas in basins. Lake shores and drainages support willow scrub and wet sedge meadows. Permafrost is continuous and has moderate ice content. Photo TJ01E34, 28 June 2001.

NOATAK LOWLAND FLOODPLAINS (NLF)

Flat, low-lying areas (19–185 m) along meandering rivers within the Noatak Lowlands. Active channel deposits are gravelly and usually barren. Soils on the adjacent floodplain range from well-drained gravelly soils to saturated loamy soils. Vegetation is dominated by tall willow and alder during early stages of floodplain development. Cottonwood and spruce forests commonly occur on well-drained soils during intermediate successional stages. Abandoned floodplains with wet organic soils support wet sedge meadows. Permafrost is discontinuous and aggrades through the successional sequence. Photo TJ01F05, 28 June 2001.

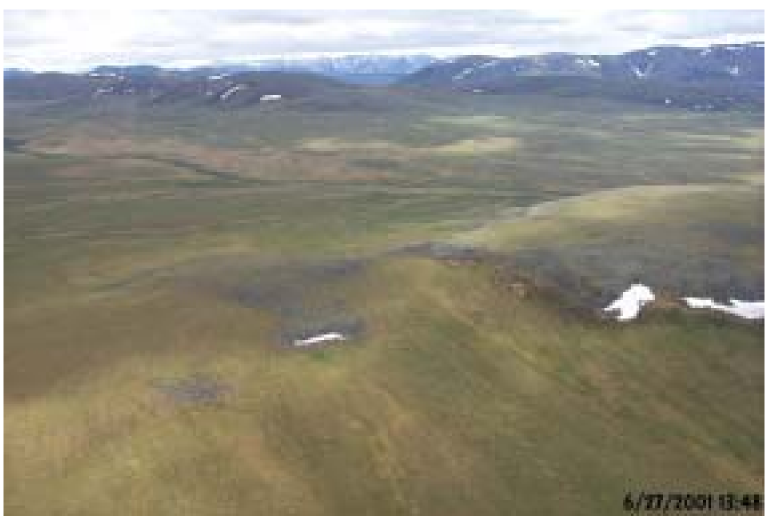
NORTHERN BAIRD FLOODPLAINS (NOBF)

Flat, low-lying areas (10–522 m) along braided and meandering rivers in valleys of the Northern Baird Mountains. Soils on the adjacent floodplain range from well-drained gravelly soils to saturated loamy soils. Vegetation is dominated by tall willow and alder during early stages of floodplain development. Cottonwood and spruce forests occur only is isolated patches. Abandoned floodplains with wet organic soils support wet sedge meadows. Permafrost is discontinuous and aggrades through the successional sequence. Photo TJ01J610, 27 June 2001.

NUKA MOUNTAINS (NUM)

Rugged mountains (497–1475 m) in the central DeLong Mountains, comprised of a complex of noncarbonate and carbonate sedimentary and mafic intrusive rocks, including chert, limestone, graywacke, mudstone, conglomerate, and diabase. Barren talus slopes predominate. Lower colluvial slopes support shrub birch-ericaceous shrub, willow scrub, and sedge-*Dryas* tundra. Drainages and steep headwater streams support low willow scrub. Permafrost is continuous and has a low ice content. Photo TJ01G10, 28 June 2001.

NUKATPIAT HILLS (NPH)



Rounded low mountains and gentle hills (630–1251 m) in the western Endicott Mountains, comprised of shale and sandstone. Most areas are mantled by gelifluction deposits and old (Sagavanirktok) glacial drift. Isolated low mountains have fellfields or dry rocky soils with sparse vegetation or *Dryas* tundra. Long gentle slopes have wet soils with tussock, birch-ericaceous shrub, and willow scrub. Drainages have willow scrub. Permafrost is continuous and has low to moderate ice content. Photo TJ01J657, 27 June 2001.

NUKATPIAT MOUNTAINS (NPM)

Rugged mountains (493–1465 m) in the western Endicott Mountains comprised of conglomerate, sandstone, and shale. Fellfields and talus cover the ridges and upper slopes and colluvium mantles the lower slopes. The fellfields are actively disturbed by frost shattering and are mostly barren with some *Dryas* tundra. Upper slopes have non-sorted stripes, wet soils, and shrub birch-ericaceous shrub and willow scrub. Lower slopes have gelifluction lobes, poorly drained organic-rich soils, and dense willow scrub. Gentle lower slopes support tussock tundra and drainages support tall willow scrub. Permafrost is continuous and has a low ice content. Photo TJ01J655, 27 June 2001.

OMAR FOOTHILLS (OUT OF PRESERVE) (OMH)

Rounded low mountains (17–682 m) in the Baird Southern Mountains, comprised of schist, argillite, quartzite, metavolcanic rocks, and marble. This highest ridgetops have fellfields or dry rocky soils with sparse vegetation or *Dryas* tundra. Adjacent upper slopes have well-drained, rocky soils with low shrubs. Lower slope positions have wetter soils with alder or willow scrub. Spruce forest is present locally on floodplains and lower slopes. [no photos].

SALMON RIVER HILLS (OUTSIDE OF PRESERVE) (SRH)

Rounded hills (126–783 m) in the central Baird Southern Mountains comprised of noncarbonate sedimentary and metamorphic rocks, including shale, sandstone, conglomerate, and quartz-mica schist. Barren rocky ridges are uncommon. Colluvial slopes have moist to wet, organic-rich soils that support *Dryas*-sedge tundra, shrub birch-ericaceous shrub, and willow scrub. Drainages have willow scrub. Headwater streams have mostly barren, gravelly floodplains with isolated open spruce forest. Permafrost is continuous with low ice content. Photo TJ01J629, 27 June 2001.

SHILIAK HILLS (SHH)

Gentle upland slopes (4–413 m) with a few rounded hills near the Noatak Delta, comprised of carbonate sedimentary and metamorphic rocks including dolomite, limestone, and marble. Isolated fellfields on hills are mostly barren, with some *Dryas* tundra. Gentle slopes with well-drained soils have isolated open spruce forest, while flat areas have poorly drained soils that support tussock tundra and shrub birch-ericaceous shrub. Permafrost is continuous with low ice content. Photo TJ01A08, 27 June 2001.

SHILIAK MOUNTAINS (SHM)

Rounded mountains (57–716 m) near the Noatak Delta, comprised of noncarbonate sedimentary and metamorphic rocks, including conglomerate, sandstone, siliceous phyllite, pelitic schist, and greenstone. Barren fellfields are common on the ridges. Colluvial slopes have moderately well-drained slopes dominated by alder scrub, willow scrub, and shrub birch-ericaceous shrub. Permafrost is continuous with low ice content. Photo TJ01A06, 27 June 2001.

SINIKTANNEYAK MOUNTAINS (SNM)

Rugged mountains (436–1502 m) in the eastern DeLong Mountains, comprised mostly of volcanic rocks including gabbro, ultramafic (dunite, olive pyroxenite), basalt with some felsic intrusive rocks. Barren fellfields and talus cover nearly the entire area. More stable slopes support *Dryas* tundra. Photo TJ01D02, 27 June 2001.

SIVUKAT MOUNTAINS (SIM)

Rounded to rugged mountains (110–986 m) in the western DeLong Mountains, comprised of noncarbonate sedimentary rocks, including sandstone, graywacke, quartzite, conglomerate. Barren fellfields and talus slopes are extensive. Colluvial slopes have moderately well-drained, acidic soils that support shrub birch-ericaceous shrub and willow scrub. Drainages have willow scrub. Permafrost is continuous and has a low ice content. Photo TJ01J749, 28 June 2001.

SKAJIT MOUNTAINS (SKM)

Rugged mountains (239–1061 m) in the central Baird Northern Mountains, comprised of carbonate sedimentary rocks, including limestone and dolostone. Barren fellfields and steep talus slopes predominate. Lower colluvial slopes have moist, nonacidic soils that support Dryas-sedge tundra. Lower slopes and alluvial fans have moist soils that support sedge-Dryas and willow scrub. Permafrost is continuous and has a low ice content. Photo TJ01J638, 27 June 2001.

SOUTHERN BAIRD FLOODPLAINS (SBF)

Flat, low lying areas (26–298 m) adjacent to braided and headwater rivers eminating from the Baird Southern Mountains. The active channels are comprised of carbonate gravels. Inactive gravel bars are covered by extensive mats of Dryas tundra, while willow and alder scrub is uncommon. Open spruce forest is common on inactive floodplains. Abandoned channels support wet sedge meadows. Permafrost is discontinuous; generally absent along the active channels and usually present in the older stages of floodplain development. Photo TJ01H15, 28 June 2001.

SQUIRREL FLOODPLAINS (OUTSIDE OF PRESERVE) (SQF)

Flat, low lying areas (9–77 m) adjacent to braided to meandering rivers in the Squirrel River Lowlands. The active channels have barren exposed gravel. Inactive gravel bars are covered by extensive mats of *Dryas* tundra, while willow and alder scrub is uncommon. Open spruce forest is common on inactive floodplains. Abandoned channels support wet sedge meadows. Permafrost is discontinuous; generally absent along the active channels and usually present in the older stages of floodplain development. [no photos].

SQUIRREL FOOTHILLS (OUTSIDE OF PRESERVE) (SQH)

Gently rounded hills (33–363 m) in the western Baird Southern Mountains, mantled by colluvium, with occasional outcrops of metamorphic carbonate rocks, including metalimestone and marble. Upper slopes have moderately well-drained, organic-rich soils that support open spruce forest. Lower, gentle slopes have poorly drained soils that support shrub birch-ericaceous shrub and shrub-tussock tundra. Headwater streams with broad, barren, gravelly floodplains are common. Permafrost is continuous and has low to moderate ice content. Photo TJ01H12, 28 June 2001.

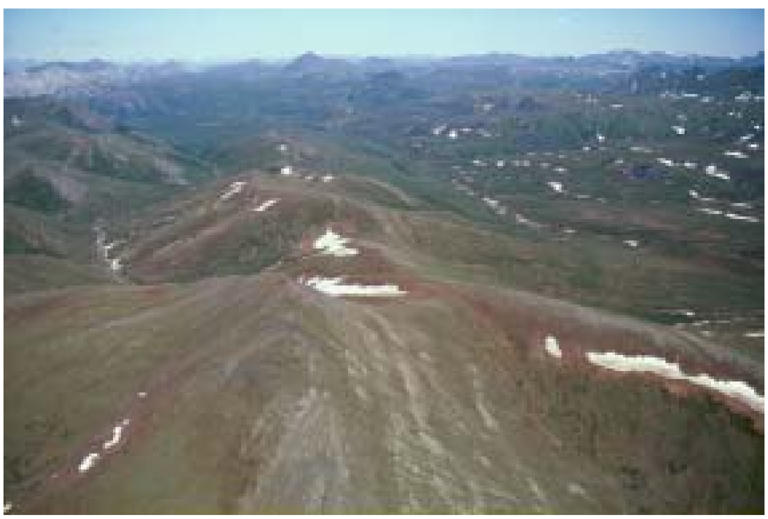
SQUIRREL MOUNTAINS (SQM)

Rounded mountains (17–985 m) in the western Baird Southern Mountains, comprised of metamorphic carbonate rocks, including metalimestone and marble. Barren fellfields and talus slopes cover most of the area. Lower, gentle slopes have poorly drained soils that support sedge-*Dryas* and willow scrub in northern portions. In southern portions, open spruce forest is extensive at lower elevations. Headwater streams with broad, barren, gravelly floodplains are common. Permafrost is continuous and has a low ice content. Photo TJ01A10, 27 June 2001.

TUKPAHLEARIK MOUNTAINS (TKM)

Rounded mountains (124–1099 m) in the central Baird Southern Mountains, comprised of mixed metamorphic and sedimentary, carbonate and noncarbonate rocks, including pelitic schist, carbonaceous quartzite, quartz conglomerate, greenstone, and marble. Barren fellfields on ridges are common. Colluvial slopes have well-drained soils that support shrub birch-ericaceous shrub and willow scrub. Open spruce forest occurs in isolated patches. Drainages have willow scrub. Permafrost is continuous and has a low ice content. Photo TJ01A28, 27 June 2001.

TUTUTALAK MOUNTAINS (TUM)

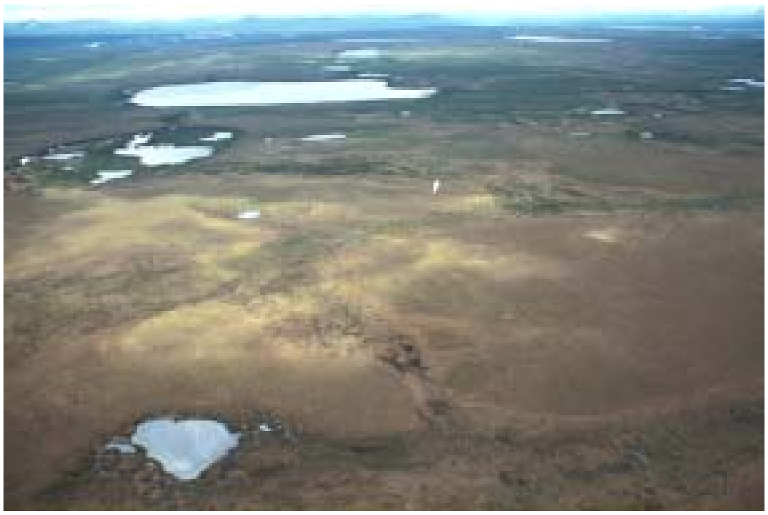


Rounded to rugged mountains (22–1360 m) in the western Baird Northern Mountains comprised of noncarbonate sedimentary rocks, including sandstone, shale, conglomerate, and calcareous phyllite. Barren fellfields on ridges are common. Colluvial slopes have moist to wet, organic-rich, acidic soils that support shrub birch-ericaceous shrub and willow scrub. Alder scrub is common on well-drained slopes. Headwater streams have broad, barren, gravelly floodplains. Permafrost is continuous and has a low ice content. Photo TJ01H05, 28 June 2001.

ULANEAK MOUNTAINS (OUTSIDE OF PRES.) (ULM)

Rugged mountains (118–1716 m) in the Schwatka Southern Mountains, comprised of carbonate rocks (limestone, dolomite, and marble) with lesser amounts of quartzite, phyllite, schist, and granitic rocks. Barren fellfields and talus are common. Upper slopes have moist rocky soils, thin organic horizons, and support shrub birch-ericaceous shrub, and alder scrub. At low elevations, open spruce forest dominates. Permafrost is continuous with low ice content. [no photos].

UPPER NOATAK BASIN (UNB)



Gently rolling upland and lowland areas (236–619 m) in the upper Noatak drainage, comprised of glacial and glaciolacustrine deposits associated with multiple glaciations. Kettle lakes are common. Gentle slopes have poorly drained, organic-rich, acidic soils with abundant frost boils and tussock tundra. Lower areas have wet, organic soils that support wet sedge meadows. Lakeshores are dominated by willow scrub, wet sedge meadows, and sedge marshes. Permafrost is continuous with low to moderate ice content. Photo TJ01C34, 27 June 2001.

UPPER NOATAK FLOODPLAIN (UNF)

Floodplain (188–570 m) of the upper Noatak River that includes the braided river, wide expanses of channel gravels, and active and inactive floodplains that are subject to frequent to occasional flooding. Exposed channel bars have gravelly to sandy, well-drained soils that support pioneering vegetation and willows. Inactive floodplains with stratified, loamy deposits support wet sedge meadows. Permafrost may be absent under the active channels, develops on the exposed bars, and is common on the adjacent vegetated floodplain. Photo TJ01J683, 27 June 2001.

UTUKOK MOUNTAINS (OUT PRESERVE) (UTM)

Rounded mountains (625–1233 m) in the central DeLong Mountains, comprised of mixed noncarbonate and carbonate sedimentary rocks, including shale, chert, and limestone. Barren fellfields on ridges and talus slopes are common. Colluvial slopes have well-drained soils that support *Dryas*-sedge tundra, shrub birch-ericaceous shrub and willow scrub. Permafrost is continuous and has a low ice content. Photo TJ01J801, 28 June 2001.

WULIK FOOTHILLS (OUTSIDE OF PRESERVE) (WUH)

Hills (142–614 m) at the western end of the Delong Mountains, comprised of shale with lesser sandstone and limestone. Convex hill summits have barren fellfields or sparse *Dryas*-lichen tundra on dry, rocky soils; permafrost here is continuous but ice content low. Lower slopes have wet, organic-rich, loamy soils with tussock, birch-ericaceous shrub, and willow scrub. Drainages have willow scrub. Permafrost on lower slopes is continuous and has low to moderate ice content. Photo TJ01J825, 28 June 2001.

WULIK MOUNTAINS (OUTSIDE OF PRESERVE) (WUM)

Rugged mountains (147–988 m) at the western end of the Delong Mountains, comprised of limestone with some sandstone and shale. Barren fellfields and talus slopes predominate. Upper colluvial slopes on carbonate rocks have moist, organic-rich, alkaline soils that support *Dryas*-lichen tundra, while lower slopes support sedge-*Dryas* tundra and willow scrub. Permafrost is continuous with low ice content. Photo TJ01J817, 28 June 2001.

REPRESENTATIVE TOPOSEQUENCES

Toposequences were developed from the literature and airphoto analysis to illustrate the changes in topography, geology, geomorphology, permafrost, soils, and vegetation across the landscape within five representative subsections chosen to cover the range of environmental gradients within the Noatak (Figures 9–13). The toposequences reveal a large variation in the local ecosystems among the various subsections. The subsections include the: Lower Noatak Floodplain, which is dominated by riverine processes (Figure 9); Nigu Glaciated Upland, which is dominated by hillsope processes on a glaciated landscape (Figure 10); Kaluktavik Uplands, which is dominated by colluvial and slope processes on bedrock and moraine material (Figure 11); the round non-glaciated Squirrel Mountains, which were formed from alkaline rocks (Figure 12); and the rounded Nukatpiat Mountains, which were formed from noncarbonate sedimentary rocks (Figure 13). Little is known about landscape relationships on intrusive mafic and old volcanic rocks.

COMPARISON OF LAND COVER CLASSES AMONG SUBSECTIONS

Comparison of the relative abundances of land cover classes (Markon and Wesser 1998) among subsections revealed that the subsections were effective at partitioning differences in vegetation and surface characteristics (Table 3). Needleleaf forests are abundant only in the Lower Noatak Floodplain, Noatak Delta, Noatak Glaciated Lowlands, Kelly Uplands, Shiliak Hills, Shiliak Mountains, and Squirrel Mountains. Tall (open or closed) and closed low alder-willow scrub is most abundant in uplands and foothills, such as Aklumayuak Foothills, Kavachurak Foothills, Kelly Uplands, and Nukatpiat Hills, and rounded mountains with noncarbonate rocks, such as Shiliak Mountains, Sivukat Mountains, and Tukpahlearik Mountains within the Baird Mountains. Open low shrub birch-ericaceous shrub and open low shrub alder-willow are most abundant in rounded noncarbonate mountains (e.g, Nukatpiat Mountains), foothills and uplands (e.g.,Nimiuktuk Hills) , glaciated lowlands (e.g., Noatak Glaciated Lowlands), and lowlands and coastal plain (e.g., Kiana Coatal Plain). Open low and dwarf shrub tussock tundra is most abundant in gently rolling upland, hills, and glaciated lowlands, such as Aklumayuak Glaciated Uplands, Anisak Uplands, Avingyak Glaciated Uplands, Cutler Hills, Kavachurak Glaciated Uplands, and Nigu Glaciated Uplands. Barren and partially vegetated areas are most abundant in rugged mountain areas, such as Avan Mountains, Misheguk Mountains, and Agashashok Mountains. Water is most prevalent in glaciated uplands and lowlands (e.g, Avingyak Glaciated Uplands), lowlands (e.g., Lower Noatak Lowlands), and floodplains (e.g., Lower Noatak Floodplain).

SUMMARY AND CONCLUSION

Landscape-level mapping of ecological units within the Noatak National Preserve was based on a review of ecological characteristics described from numerous field studies and the differentiation of important large-scale landscape components, particularly physiography and geology. The mapping, done within the framework of the broader ecoregion map of Alaska, produced 6 sections and 57 subsections within the Brooks Range, 2 sections and 7 subsections within the Kobuk Ridges and Valleys, and 2 sections and 2 subsections within the Kotzebue Sound Lowlands. The units were differentiated on the basis of dominant geologic and geomorphic processes, including: marine and estuarine processes along the coast, thaw-lake processes on the coastal plain and lowlands, fluvial processes on floodplains, colluvial and slope processes on hills, and frost riving and slope processes on mountains. Much of the diversity among subsections within the mountains was driven by the wide variation in bedrock structure and chemistry, ranging from sedimentary carbonate rocks to sedimentary noncarbonate rocks and ultramafic intrusive volcanic rocks. Large differences among subsections in the relative abundances of land cover classes (based on previous mapping) revealed that the mapping was effective at partitioning the abundance of land cover classes. The subsection map probably also is effective at partitioning floristic differences, based on limited data obtained from field studies. Overall, it appears that the landscape-level partitioning of ecological patterns and processes will provide a useful way to stratify sampling for the upcoming biological inventory and monitoring program.

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Table 1. List of sections, subsections, differentiating characteristics, and areas of landscape-level ecological units in the Noatak National Preserve (26,582 km²). Areas are for portions of the subsections within the Preserve.

Section	Subsection[1]	Physiography	Geology	Code	Area (km²)
BROOKS RANGE ECOREGION					
DeLong Mountains	Avan Mountains	Mountains-rugged	Intrusive mafic rocks	AVM	360
	Kugururok Mountains	Mountains-rugged	Sedimentary, noncarbonate rocks	KUM	487
	Kelly Mountains	Mountains-rugged	Sedimentary, carbonate rocks	KEM	922
	Kokolik Mountains	Mountains-rugged	Sedimentary, noncarbonate rocks	KOM	198
	Misheguk Mountains	Mountains-rugged	Intrusive mafic and old volc. mafic rocks	MIM	661
	Imikneyak Mountains	Mountains-rounded	Complex of intrusive mafic and sedimentary, noncarbonate rocks	IMM	405
	Kaluktavik Mountains	Mountains-rounded	Sedimentary, noncarbonate rocks	KLM	390
	Kaluktavik Uplands	Uplands	Sedimentary, noncarbonate rocks	KLU	875
	Bastille Mountains	Mountains-rugged	Complex of old mafic volcanic, non-carbonate and carbonate sedimentary rocks	BAM	577
	Sivukat Mountains	Mountains-rounded	Sedimentary, noncarbonate rocks	SIM	68
	Ikalukrok Mountains	Mountains-rounded	Sedimentary, noncarbonate rocks	IKM	26
	Anisak Mountains	Mountains-rugged	Complex of old mafic volcanic, non-carbonate and carbonate sedimentary rocks	ANM	703
	Nuka Mountains	Mountains-rugged	Complex of old mafic volcanic, non-carbonate and carbonate sedimentary rocks	NUM	467
	Siniktanneyak Mountain	Mountains-rugged	Complex of old mafic volcanic, non-carbonate and carbonate sedimentary rocks	SNM	206
	Iggiruk Mountains	Mountains-rounded	Sedimentary, mixed noncarbonate and carbonate rocks	IGM	473
	Nimiuktuk Hills	Hills	Sedimentary, noncarbonate rocks; Quaternary colluvium	NIH	292
	Kugururok Uplands	Uplands	Quaternary, colluvium	KUU	408
	Kelly Uplands	Uplands	Quaternary, colluvium	KEU	422
	Delong Mountain Floodplains[1]	Floodplains	Quaternary Alluvium	DMF	276
Endicott Mountains	Ipnavik Mountains	Mountains-rugged	Sedimentary, noncarbonate rocks	IPM	176
	Aniuk Mountains	Mountains-rounded	Complex of sedimentary, noncarbonate and carbonate rocks and mafic intrusive rocks	AIM	1256
	Nukatpiat Mountains	Mountains-rounded	Sedimentary, noncarbonate rocks	NPM	259
	Nukatpiat Hills	Hills	Sedimentary, noncarbonate rocks	NPH	139
	Nigu Glaciated Uplands	Glaciated Uplands	Quaternary, glacial deposits	NGU	153
	Endicott Mountain Floodplains[1]	Floodplains	Quaternary Alluvium	EMF	5
Noatak Basin	Cutler Hills	Hills	Sedimentary, carbonate rocks	CUH	67
	Avingyak Hills	Hills	Sedimentary, noncarbonate rocks	AGH	297
	Avingyak Glaciated Uplands	Glaciated Uplands	Quaternary, glacial deposits	AGU	231

Table 1. (Continued).

Section	Subsection[1]	Physiography	Geology	Code	Area (km²)
	Kavachurak Glaciated Uplands	Glaciated Uplands	Quaternary, glacial deposits	KGU	588
	Aklumayuak Glaciated Uplands	Glaciated Uplands	Quaternary, glacial deposits	AKU	307
	Middle Noatak Uplands	Hills	Sedimentary, noncarbonate rocks; Quaternary, noncarbonate deposits	MNU	543
	Upper Noatak Basin	Lowlands	Quaternary, lowlands (glaciolacustrine)	UNB	2473
	Anisak Uplands	Hills	Quaternary, lowlands (glaciolacustrine)	ANU	389
	Iggiruk Glaciated Uplands	Hills	Quaternary, lowlands (glaciolacustrine)	IGU	984
	Middle Noatak Fldpln	Floodplain	Quaternary, alluvium	MNF	125
	Upper Noatak Fldpln	Floodplain	Quaternary, alluvium	UNF	284
	Noatak Basin Floodpl.[1]	Floodplain	Quaternary, alluvium	NBF	228
Baird Northern Mountains	Eli Foothills	Hills	Quaternary, colluvium	ELH	579
	Eli Mountains	Mountains-rugged	Sedimentary, carbonate rocks	ELM	307
	Asik Mountain	Mountains-rounded	Intrusive, mafic and ultramafic rocks	ASM	61
	Kikmiksot Mountains	Mountains-rugged	Intrusive, mafic and ultramafic rocks	KIM	191
	Tututalak Mountains	Mountains-rounded	Sedimentary, noncarbonate rocks	TUM	1680
	Agashashok Mountains	Mountains-rugged	Sedimentary, carbonate rocks	AAM	263
	Nakolik Mountains	Mountains-rounded	Sedimentary, carbonate rocks	NAM	298
	Aklumayuak Foothills	Hills	Sedimentary, noncarbonate rocks	AKH	1345
	Anaktok Mountains	Mountains-rounded	Sedimentary, carbonate rocks	ATM	62
	Kunyanak Mountains	Mountains-rounded	Sedimentary, carbonate rocks	KYM	357
	Angayukaqsraq Mountains	Mountains-rugged	Complex of meta sedimentary and metavolcanic rocks	AYM	374
	Natmotirak Mountains	Mountains-rounded	Mixed metamorphic, carbonate and noncarbonate rocks	NTM	397
	Natmotirak Foothills	Hills	Mixed metamorphic, carbonate and noncarbonate rocks	NTH	648
	Skajit Mountains	Mountains-rugged	Sedimentary, carbonate rocks	SKM	79
	Imelyak Foothills	Hills	Sedimentary, mixed carbonate and noncarbonate rocks	IMH	762
	Northern Baird Floodplain[1]	Floodplain	Quaternary, alluvium	NOBF	158
Baird Southern Mountains	Squirrel Mountains	Mountains-rugged	Sedimentary, carbonate rocks	SQM	254
	Tukpahlearik Mountains	Mountains-rounded	Complex of metamorphic and sedimentary, carbonate and noncarbonate rocks	TKM	17
	Akiak Mountains	Mountains-rugged	Sedimentary, carbonate rocks	AKM	13
Schwatka Northern Mountains	Kavachurak Mountains	Mountains-rugged	Sedimentary, carbonate rocks	KVM	510
	Kavachurak Foothills	Hills	Sedimentary, noncarbonate rocks	KVH	297

Table 1. (Continued).

Section	Subsection[1]	Physiography	Geology	Code	Area (km²)
KOBUK RIDGES AND VALLEYS					
Noatak Lowlands	Lower Noatak Lowlands	Lowlands	Quaternary, lowlands	LNL	399
	Lower Noatak Floodplain	Floodplains	Quaternary, alluvium	LNF	127
	Noatak Glaciated Lowlands	Glaciated Lowlands	Quaternary, glacial deposits	NGL	655
	Noatak Lowland Floodplains[1]	Floodplain	Quaternary, alluvium	NLF	77
	Shiliak Mountains	Rounded Mountains	Metamorphic and sedimentary, noncarbonate rocks	SHM	89
	Shiliak Hills	Hills	Quaternary, colluvium; sedimentary carbonate rocks	SHH	172
Kiana Hills	Kiana Lowlands	Lowlands	Quaternary, lowlands	KIL	25
KOTZEBUE SOUND LOWLANDS					
Krusen-stern Coast	Noatak Delta	Delta	Quaternary, marine	NOD	1
Kobuk-Noatak Coastal Plain	Kiana Coastal Plain	Coastal Plain	Quaternary, lowland	KCP	25

[1] Floodplains within subsections were further delineated as Detailed Subsections. Because of the ecological similarity of the separate floodplains within a Section and to reduce creation of numerous extra classes, all floodplains with a section have the same name. Also note that the area for the subsection does not include the area of the floodplains (detailed subsections) within them.

Table 2. Distribution (% of subsection area) of land cover types among subsections sorted by physiography and geology, Noatak National Preserve, northwestern Alaska.

Subsection	Closed Needleleaf Forest	Open Needleleaf Forest	Needleleaf Woodland	Tall Open And Closed Alder/Willow	Closed Low Shrub - Alder/Willow	Closed Low Shrub - Birch/ Ericaceous	Open Low Shrub - Alder/Willow	Open Low Shrub - Birch/ Ericaceous	Open Low And Dwarf Shrub Tussock Tundra	Dwarf Shrub Tundra/ Dwarf Shrub Peatland	Open Dwarf Shrub - Talus/ Lichen	Moist Or Dry Herbaceous	Wet Herbaceous	Sparsely Vegetated	Barren	Snow/ Ice/ Cloud	Clear Water	Turbid Water	Shadow
RUGGED MOUNTAINS-NONCARBONATE																			
Avan Mountains	<1	<1	<1	2	<1	<1	3	2	4	4	15	13	1	18	36	0	<1	<1	<1
Angayukaqsraq Mountains	0	0	0	<1	<1	<1	2	2	4	8	20	10	<1	10	41	0	<1	0	1
Anisak Mountains	<1	<1	<1	1	2	1	8	11	13	11	14	17	<1	9	12	0	<1	<1	<1
Bastille Mountains	<1	<1	<1	3	2	1	10	5	8	8	17	15	<1	9	21	0	0	<1	<1
Ipnavik Mountains	0	0	0	<1	1	<1	10	19	12	11	6	3	1	12	19	3	1	1	2
Kikmiksot Mountains	1	1	1	2	3	1	10	9	8	6	16	13	1	10	17	0	<1	<1	1
Kokolik Mountains	<1	<1	<1	3	1	1	9	4	8	13	12	18	<1	18	12	0	0	<1	<1
Kugururok Mountains	<1	1	1	3	2	4	13	11	15	11	8	13	1	6	12	0	<1	<1	<1
Misheguk Mountains	<1	<1	<1	4	<1	<1	5	3	4	4	17	14	<1	18	31	0	0	<1	<1
Nuka Mountains	<1	<1	<1	1	<1	<1	3	6	3	11	22	8	<1	16	29	0	<1	<1	1
Siniktanneyak Mountain	0	0	0	1	<1	<1	3	1	1	13	18	4	<1	14	44	0	1	<1	1
RUGGED MOUNTAINS-CARBONATE																			
Agashashok Mountains	2	2	1	3	<1	1	7	6	7	5	12	7	1	15	30	0	<1	<1	1
Akiak Mountains	<1	<1	<1	0	3	1	6	29	16	7	1	4	2	10	7	0	2	0	11
Eli Mountains	1	2	2	2	1	1	8	9	9	3	7	7	1	15	30	0	<1	0	1
Kavachurak Mountains	0	0	0	1	2	<1	7	11	7	14	13	5	1	21	10	2	1	<1	7
Kelly Mountains	<1	<1	<1	3	1	1	4	3	6	6	11	7	1	13	43	0	<1	<1	<1
Skajit Mountains	0	0	0	<1	2	<1	4	9	11	5	4	5	1	14	31	<1	<1	2	12
Squirrel Mountains	2	7	3	1	1	<1	11	9	9	2	3	8	1	15	28	0	1	<1	<1
ROUNDED MOUNTAINS – NONCARBONATE																			
Aniuk Mountains	0	0	0	1	2	<1	11	24	24	11	4	6	1	6	8	2	<1	<1	1
Asik Mountain	<1	1	2	1	<1	1	9	23	21	2	6	15	<1	9	9	0	<1	<1	<1
Iggiruk Mountains	0	0	0	1	3	3	15	15	17	8	7	18	<1	6	7	0	<1	<1	<1
Ikalukrok Mountains	<1	<1	<1	3	1	<1	2	3	22	17	10	12	7	10	10	0	<1	0	2
Imikneyak Mountains	<1	<1	<1	2	4	2	13	8	8	8	16	15	<1	8	16	0	<1	<1	<1
Natmotirak Mountains	<1	<1	<1	2	4	1	14	22	22	11	1	3	<1	8	5	1	2	<1	6
Nukatpiat Mountains	0	0	0	4	5	<1	25	17	13	10	4	1	2	8	5	<1	<1	0	5
Shiliak Mountains	1	4	2	10	2	5	20	22	12	13	2	5	1	1	2	0	<1	0	<1
Sivukat Mountains	<1	1	2	7	3	<1	2	6	13	16	12	13	9	4	8	0	<1	0	3
Tukpahlearik Mountains	0	<1	<1	2	8	1	19	15	9	12	9	4	0	5	5	0	0	<1	9
Tututalak Mountains	<1	1	1	2	3	4	21	19	19	8	3	6	<1	4	7	0	<1	<1	1

Table 2. (Continued).

Subsection	Closed Needleleaf Forest	Open Needleleaf Forest	Needleleaf Woodland	Tall Open And Closed Alder/Willow	Closed Low Shrub - Alder/Willow	Closed Low Shrub - Birch/ Ericaceous	Open Low Shrub - Alder/Willow	Open Low Shrub - Birch/ Ericaceous	Open Low And Dwarf Shrub Tussock Tundra	Dwarf Shrub Tundra/ Dwarf Shrub Peatland	Open Dwarf Shrub - Talus/ Lichen	Moist Or Dry Herbaceous	Wet Herbaceous	Sparsely Vegetated	Barren	Snow/ Ice/ Cloud	Clear Water	Turbid Water	Shadow
ROUNDED MOUNTAINS – CARBONATE																			
Anaktok Mountains	<1	0	0	2	6	1	19	13	9	8	12	11	<1	6	7	0	0	<1	7
Kaluktavik Mountains	0	0	0	3	3	3	16	12	11	9	8	12	<1	7	17	0	0	<1	<1
Kunyanak Mountains	0	0	0	<1	3	<1	6	12	9	7	3	9	<1	16	33	0	<1	<1	2
Nakolik Mountains	<1	<1	<1	2	2	1	18	14	12	11	6	12	<1	8	12	0	0	<1	1
FOOTHILLS, HILLS, AND UPLANDS																			
Imelyak Foothills	<1	<1	<1	1	1	<1	11	18	27	17	3	9	<1	6	3	1	1	<1	1
Eli Foothills	<1	2	3	1	1	1	13	32	22	5	<1	11	2	<1	3	0	1	<1	1
Kavachurak Foothills	0	0	0	6	7	<1	29	13	18	16	2	3	<1	2	1	<1	1	0	1
Aklumayuak Foothills	0	0	<1	2	7	3	28	28	15	5	2	7	<1	2	2	0	<1	<1	<1
Natmotirak Foothills	0	0	0	<1	7	1	27	24	26	4	1	8	<1	1	2	<1	<1	<1	<1
Avingyak Hills	0	0	0	<1	1	<1	8	14	24	13	4	25	<1	4	6	0	<1	<1	<1
Cutler Hills	0	0	0	<1	1	<1	2	15	37	7	4	18	<1	6	8	0	<1	<1	<1
Nimiuktuk Hills	0	0	0	4	6	3	32	20	13	4	2	8	<1	2	2	0	<1	1	<1
Nukatpiat Hills	0	0	0	2	10	<1	37	17	23	6	<1	1	<1	2	1	<1	1	0	1
Shiliak Hills	1	5	3	1	1	<1	11	49	15	2	1	4	1	2	3	0	<1	<1	0
Anisak Uplands	0	0	0	1	2	1	16	25	30	6	2	15	<1	1	1	0	<1	1	<1
Kaluktavik Uplands	<1	<1	1	2	1	3	30	27	22	4	1	8	<1	1	1	0	<1	<1	<1
Iggiruk Glaciated Uplands	0	0	0	<1	2	1	15	25	25	9	<1	19	<1	<1	<1	0	3	1	0
Kelly Uplands	1	2	6	7	3	2	10	22	17	4	1	10	8	4	3	0	2	<1	<1
Kugururok Uplands	<1	1	2	4	3	3	29	21	16	4	1	7	<1	4	2	0	<1	1	<1
Middle Noatak Uplands	<1	<1	<1	1	2	1	30	29	18	4	<1	9	<1	<1	<1	0	4	1	<1
GLACIATED UPLANDS AND LOWLANDS																			
Avingyak Glaciated Uplands	0	0	0	<1	2	<1	2	5	25	20	2	29	<1	1	1	0	11	2	<1
Aklumayuak Glaciated Uplands	0	0	0	<1	3	1	22	31	29	2	<1	13	<1	<1	<1	0	<1	<1	<1
Kavachurak Glaciated Uplands	0	0	0	1	1	<1	9	12	30	25	<1	17	1	<1	<1	<1	4	<1	<1
Nigu Glaciated Uplands	0	0	0	1	2	<1	16	29	41	4	<1	1	<1	<1	<1	<1	4	0	<1
Noatak Glaciated Lowlands	2	4	5	2	2	1	18	31	16	4	<1	6	4	1	1	0	4	<1	<1
LOWLANDS AND COASTAL PLAIN																			
Kiana Lowlands	1	3	1	3	2	1	16	57	12	2	<1	2	<1	<1	<1	0	<1	0	0
Kiana Coastal Plain	<1	2	1	4	1	<1	15	57	13	2	<1	2	1	<1	<1	0	1	<1	0
Lower Noatak Lowlands	<1	<1	1	<1	2	<1	12	27	18	11	<1	14	5	<1	<1	0	8	<1	0
Upper Noatak Basin	0	0	0	<1	3	<1	7	14	51	4	<1	15	1	<1	<1	<1	1	2	<1
FLOODLPAINS AND DELTAS																			
Lower Noatak Floodplain	6	17	15	<1	3	<1	10	4	1	1	3	4	4	2	21	0	7	3	0
Upper Noatak Floodplain	<1	<1	<1	2	10	<1	15	4	11	11	2	15	2	2	10	<1	7	9	<1
Noatak Delta	0	6	4	2	4	<1	10	4	1	<1	0	1	1	1	0	0	66	<1	0
All	<1	1	1	2	3	1	14	17	20	8	5	11	1	5	9	<1	1	1	1

Appendix 1. Number of observations in literature database for each author by subsection and landscape component.

Subsection	Component	Beikman et al. 1980	Brown et al. 1997	Curtis et al. 1984	Ellersieck et al. 1984	Hamilton 1984a	Hamilton 1984b	Hamilton 1994a	Hamilton 1994b	Karl et al. 1989	Mayfield et al. 1994	Moore et al. 1994	Mull et al. 1987	Ugolini and Walters 1974	Young 1974	Binkley et al. 1997	Barnes 1987	Hamilton 2001	Hamilton and Van Etten 1984	Elias et al. 1999	Suarez et al. 1999	Rupp et al. 2001	Eisner and Collinvaux 1992	Grand Total
AAM	Geology									1														1
AGH	Geology												3											3
AGU	Geomorphology						1							5										6
	Soil													4										4
	Vegetation													3	4									7
	Paleoecology																						1	1
AIM	Geology												5											5
AKH	Geology									3														3
AKU	Geomorphology						1																	1
ANM	Geology										10													10
ANU	Geomorphology							1																1
ASM	Geology												1											1
ATH	Geology									4														4
ATM	Geology									2														2
AVM	Geology			3																				3
AYM	Geology									4														4
BAM	Geology			9																				9
camp ix	Vegetation														5									5
camp vi	Vegetation														3									3
CUH	Geology												1											1
DMF	Geology			1																				1
	Soil															1								1
	Vegetation															5								5
ELH	Geology									1														1
ELM	Geology									3														3
EMF	Geomorphology								1															1
General	Vegetation														16							1		17
IGM	Geology										9													9
IGU	Geomorphology								1															1
IKM	Geology	1																						1
IMH	Geology												3											3
IMM	Geology				7																			7
IPM	Geology												3											3
KEL	Geology			1																				1
KEM	Geology			6																				6
KGL	Geology			1																				1
KIH	Geology									5														5
KIL	Geology									1														1
KIM	Geology									3														3
KLH	Geology			3																				3
KLM	Geology			2																				2
KOM	Geology			5																				5
KUM	Geology			7																				7
KUU	Geomorphology						2																	2
KVH	Geology												1											1
KYM	Geology									3														3
LNF	Geology												1											1

Appendix 1. (Continued).

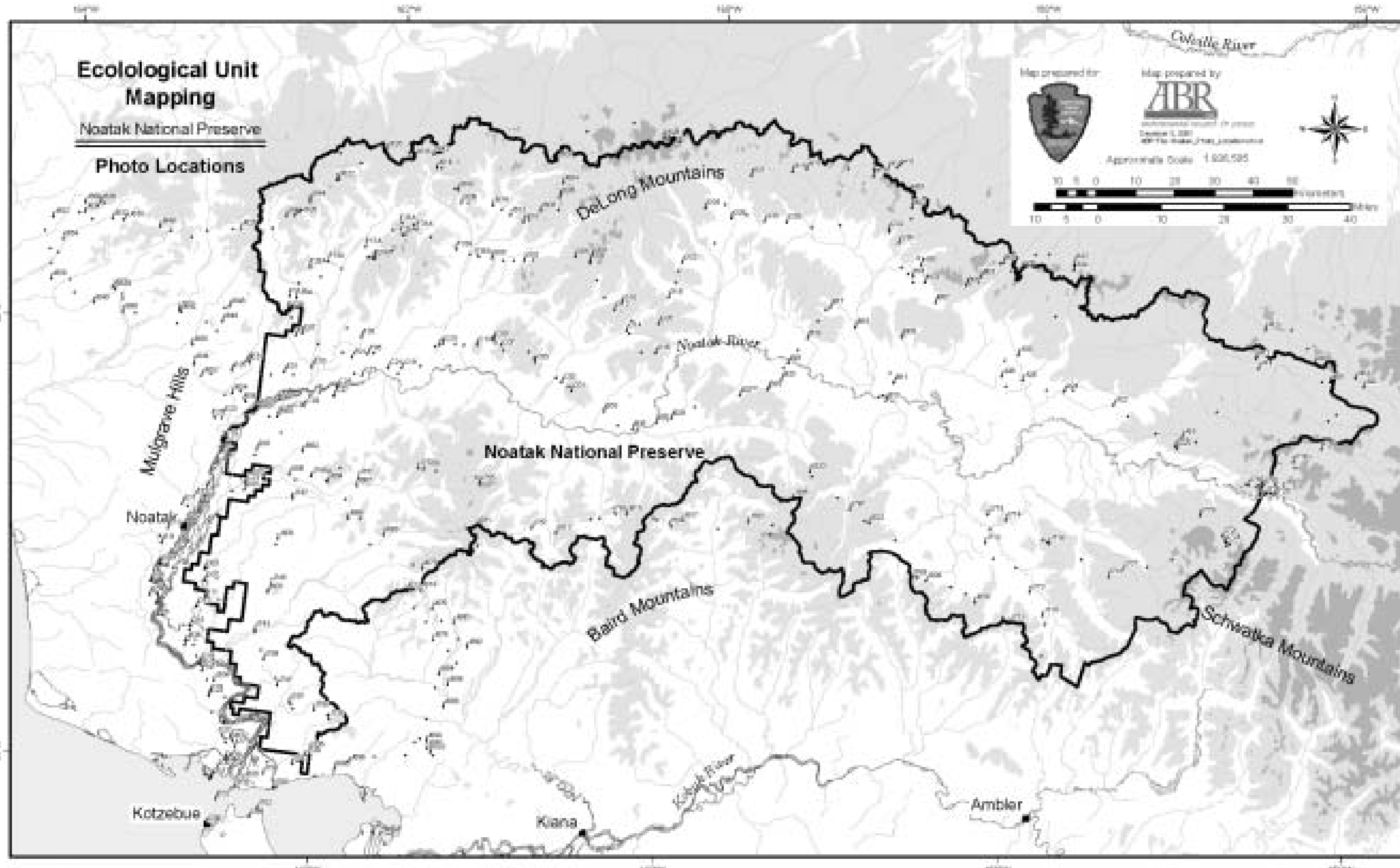
Subsection	Component	Beikman et al. 1980	Brown et al. 1997	Curtis et al. 1984	Ellersieck et al. 1984	Hamilton 1984a	Hamilton 1984b	Hamilton 1994a	Hamilton 1994b	Karl et al. 1989	Mayfield et al. 1994	Moore et al. 1994	Mull et al. 1987	Ugolini and Walters 1974	Young 1974	Binkley et al. 1997	Barnes 1987	Hamilton 2001	Hamilton and Van Etten 1984	Elias et al. 1999	Suarez et al. 1999	Rupp et al. 2001	Eisner and Collinvaux 1992	Grand Total
	Geomorphology													1										1
	Vegetation													2	5									7
LNL	Geology											1												1
	Geomorphology		1											3	1									5
	Soil													4										4
	Vegetation													8										8
MIM	Geology			5																				5
MNF	Geomorphology								1															1
MNU	Geology				2																			2
	Vegetation														2									2
NAM	Geology									3														3
NBF	Geology									1														1
NGU	Geomorphology					3																		3
	Vegetation														7									7
NID	Geology												1											1
NIH	Geology										4													4
NOBF	Geology									1														1
	Geomorphology								1															1
	Vegetation																				1			1
NOD	Geomorphology													4										4
	Soil													3										3
	Vegetation													5	2									7
NPM	Geology												2											2
	Vegetation														6									6
NSM	Geology												2											2
NTH	Geology												2											2
NTM	Geology												1											1
NUM	Geology										5													5
SHH	Geology											2		1										3
	Soil													3										3
	Vegetation													3										3
SHM	Geology									2														2
SIM	Geology	1																						1
SKM	Geology											1												1
SNM	Geology												4											4
	Geomorphology													3										3
	Soil													1										1
	Vegetation														1									1
SOBF	Geology									1														1
SQH	Geology									1														1
SQM	Geology									1														1
SRH	Geology									1														1
TKM	Geology									5														5
TUM	Geology									5														5
UNB	Geomorphology								4								1	3	1	1				10
	Vegetation														4									4
UNF	Geomorphology								1															1
	Vegetation																	3						3
UTM	Geology											1												1
Grand Total		2	1	43	9	3	4	1	9	51	28	5	30	53	56	6	1	6	1	1	1	1	1	313

Appendix 2. Classification and broad groupings of bedrock geology that emphasizes differences weathering, ruggedness, and soil chemistry. Partially derived from ADGGS (1983).

Class	Description
Sedimentary-carbonate (Sc)	Sedimentary rocks dominated by carbonate materials, primarily calcite ($CaCO_3$) and magnesite (Mg CO_3). Rocks include limestone (Ca-rich), dolostone (Ca, Mg-rich), and calcareous sandstone. Soils formed from these rocks generally are alkaline and rich in humus. Phosphorus availability is reduced by fixation in various calcium phosphate compounds (hydroxyapatite, flouroapatite). In addition, at pH values above 7, excess calcium may hinder phosphorus absorption and utilization of plants.
Sedimentary-noncarbonate (Sn)	Sedimentary rocks other than limestone, including conglomerate (pebble-cobble rich), sandstone (sand-rich), graywacke, shale (clay-rich), argillite (clay minerals) and chert (SiO_2). Generally low Ca and Na and high Al concentrations lead to acid soils. High soluble Al concentrations can lead to plant growth problems (root growth stopped at Al as low as 1 mg/L). Phosphorus mostly fixed as aluminum and iron phosphates in acid soils.
Sedimentary, mixed (Sm)	Sedimentary assemblage of both carbonate and noncarbonate rocks.
Quaternary, alluvium (Qa)	Quaternary sediments on alluvial plains, primarily restricted to Holocene floodplains. Primarily differentiates active and inactive floodplains with early to mid-late successional vegetation. Soils are still affected by frequent to rare flooding and sedimentation and usually are circumneutral to alkaline. Includes glacial outwash deposits.
Quaternary, colluvium (Qc)	Quaternary sediments that are derived mostly from colluvial processes on hillsides. The soils on upper slopes tend to be rockier and better drained, whereas, on lower slopes soils have more fines and are wetter. Areas include occasional bedrock outcrops.
Quaternary, lowland (Qx)	Quaternary sediments in lowland areas derived from complex processes including colluvial, eolian, alluvial, lacustrine, glaciolacustrine, and marine. For coastal plains, basins, and valleys with fine-grained sediments and where depositional processes are inactive.
Quaternary, eolian (Qe)	Quaternary sediments that are derived from wind blown material and includes loess, sand dunes, and sand sheets. In some areas with more soils information carbonate (Qec) and noncarbonated (Qen) can be differentiated: younger eolian sediments tend to have alkaline soils from higher carbonate concentrations, whereas, older eolian sediments tend to have acidic soils due to leaching of carbonates.
Quaternary, glacial (Qg)	Quaternary sediments related to glacial activity, primarily moraines and glacial drift. The glacial terrain has highly heterogenous slopes, soils, and hydrolography, often with kettle lakes.
Quaternary, lacustrine (Ql)	Quaternary sediments that are derived from active lacustrine or glaciolacustrine processes. Soils typically are circumneutral to alkaline.
Quaternary, marine (Qm)	Quaternary sediments of marine or eolian origin that are high in halites (NaCl). Includes gravel and sandy beaches, backshore dunes, barrier islands, tidal flats, coastal deltas. Soils are slightly brackish to brackish.
Volcanic-felsic-younger (Vfy)	Felsic extrusive igneous rocks that have light-colored mineral assemblages rich in silica content, such a quartz (SiO_2, highly resistant to weathering), orthoclase feldspar ($KalSi_3O_8$), and muscovite mica (sheet silicates, Kal_3Si3O10). Rocks include rhyolite, felsite, rhyocacite, trachyte, and quartz trachyte. Soils are absent to very thin and acidic.
Volcanic-felsic-older (Vfo)	Similar to above, except rocks formed during Tertiary or older periods and are more highly weathered. Weathering forms acidic soils.
Volcanic-mafic-younger (Vmy)	Mafic and intermediate extrusive igneous rocks have dark-colored mineral assemblages with low silica content and high metallic bases, such as amphiboles (Ca, Na, Mg, Fe rich silicates), plagiocase feldspar ($NaAlSi_3O_8$, $CaAl_2Si_2O_8$), pyroxenes and olivine (high in Fe, Mg, Ca orthosilicates) and biotite mica (sheet silicate rich in Fe and Mg). The iron- and magnesium-rich minerals are more easily weathered than granites. Mafic rock types include basalts and diabase and intermediate rocks include andesite and dacite. Soils on the Quaternary age rocks, are absent or thin.

Appendix 2. (Continued).

Class	Description
Volcanic-mafic-older (Vmo)	Similar to above except rocks were formed during the Tertiary or older periods and, therefore, are more highly weathered.
Volcanic-pyroclastics (Vp)	Detrital volcanic materials that have been explosively or aerially expelled from a volcanic vent. Deposits include volcanic conglomerates, tuffs, ash, ash-flow, and all other tephras.
Intrusive-felsic (If)	Felsic and meta- plutonic rocks that have mineral assemblages dominated by light-colored minerals such as quartz, orthoclase feldspars, and muscovite. Rocks include granite, granodiorite and syenite. Metaplutonic rocks include granitic gneiss, serpentinite, ultramafic gneiss, and soapstone. Soils generally are acidic and podzolization is more fully developed.
Intrusive-mafic (Im)	Intermediate, mafic and ultramafic plutonic rocks that have dark-colored mineral assemblages with significant amounts of iron and magnesium. Intermediate rocks dominated by plagioclase feldspars include diorite, quartz-diorite, monzodiorite, and quartz-monzodiorite. Mafic rocks dominated by pyroxene and plagioclase feldspars include gabbro and olivine-gabbro. Ultramafic rocks are rich in olvine and pyroxene and include hornblendite, pyroxenite, dunite, peridotite, and serpentine. Soils tend to be neutral to alkaline.
Metamorphic-carbonate (Mc)	Metacarbonate sedimentary rocks consisting essentially of calcite and/or dolomite. Rock is primarily marble.
Metamorphic-noncarbonate (Mn)	A diverse group of metasedimentary, metapelitic, and metavolcanic rocks that lack carbonates. Metasedimentary include metaconglomerate, metagraywacke, phyllite, slate, quartzite, and schist (K, Mg, Fe, Al rich), while marble may be a minor component. Metavolcanic rocks include greenschist, greenstones, schists, amphibolite, olivine, and phyllite.
Metamorphic-mixed	Metamorphic assemblage of both carbonate and noncarbonate rocks.
Bedrock Complex (BC)	Complex mixtures of highly interspersed patches of rocks with widely varying lithologies. Sedimentary-mixed and Metamorphic mixed when rock complex has more similar lithologies.



Appendix 3. Map of locations of oblique aerial photos in the Noatak National Preserve, northwestern Alaska.

Appendix 4. Summary of subsection areas in the Noatak National Preserve and adjacent areas, northwestern Alaska.

		Within Noatak National Preserve				Total in Northwest Area	
Subsection and Detailed Subsection[1]	Code	Number of Polygons	Area (ha)	Area (ac)	Area (%)	Area (ha)	Area (ac)
Agashashok Mountains	AAM	1	26340	65086	1.0	40821	100867
Aklumayuak Foothills	AKH	1	134468	332267	5.1	138223	341544
Akiak Mountains	AKM1	17	1299	3209	0.0	175544	433763
Aklumayuak Glaciated Uplands	AKU	2	30720	75909	1.2	30720	75909
Ambler Foothills	AMH	0	0	0	0	21746	53733
Ambler Mountains	AMM	0	0	0	0	104882	259160
Anaktok Mountains	ATM1	2	6166	15235	0.2	15748	38912
Angayukaqsraq Mountains	AYM1	2	1422	3514	0.1	18396	45456
Anisak Mountains	ANM	1	70280	173660	2.6	70280	173660
Anisak Uplands	ANU	3	38897	96113	1.5	38897	96113
Aniuk Mountains	AIM	2	125634	310436	4.7	128283	316982
Asik Mountain	ASM	1	6063	14982	0.2	6063	14982
Avan Mountains	AVM	1	35962	88861	1.4	35962	88861
Avingyak Glaciated Uplands	AGU	1	23093	57062	0.9	23093	57062
Avingyak Hills	AGH	1	29720	73436	1.1	29720	73436
Bastille Mountains	BAM	3	57728	142643	2.2	60065	148419
Cutler Hills	CUH	1	6662	16463	0.3	6662	16463
Delong Mountain Floodplains*	DMF	11	27640	68298	1.0	29063	71813
Eli Foothills	ELH	2	57864	142981	2.2	60346	149113
Eli Mountains	ELM	4	30743	75964	1.2	30743	75964
Endicott Mountain Floodplains*	EMF	1	514	1269	0.0	514	1269
Iggiruk Mountains	IGM	1	47321	116929	1.8	47321	116929
Iggiruk Glaciated Uplands	IGU	3	98373	243076	3.7	98373	243076
Ikalukrok Mountains	IKM	2	2561	6328	0.1	26451	65359
Imelyak Foothills	IMH	1	76168	188208	2.9	81240	200742
Imikneyak Mountains	IMM	5	40471	100002	1.5	40471	100002
Ipnavik Mountains	IPM	13	17579	43436	0.7	99366	245531
Kaluktavik Mountains	KLM	5	38974	96304	1.5	38974	96304
Kaluktavik Uplands	KLU	1	87526	216274	3.3	87526	216274
Kavachurak Foothills	KVH	1	29740	73487	1.1	42730	105584
Kavachurak Glaciated Uplands	KGU	2	58847	145410	2.2	72579	179341
Kavachurak Mountains	KVM	1	51000	126020	1.9	91273	225531
Kelly Mountains	KEM	11	92172	227754	3.5	107118	264685
Kelly Uplands	KEU	4	42175	104213	1.6	42678	105457
Kiana Coastal Plain	KCP	1	2465	6091	0.1	35313	87257
Kiana Hills	KIH	0	0	0	0	80067	197844
Kiana Lowlands	KIL	1	2535	6265	0.1	59641	147371
Kikmiksot Mountains	KIM	1	19096	47185	0.7	19096	47185
Kokolik Mountains	KOM	3	19842	49029	0.7	73315	181159
Kugururok Mountains	KUM	7	48688	120305	1.8	50787	125492
Kugururok Uplands	KUU	3	40802	100821	1.5	40802	100821
Kunyanak Mountains	KYM	3	35731	88288	1.3	52998	130957
Lower Noatak Floodplain	LNF	5	12666	31298	0.5	58388	144276
Lower Noatak Lowlands	LNL	3	39937	98684	1.5	93145	230158
Middle Noatak Floodplain*	MNF	1	12476	30828	0.5	12476	30828

Appendix 4. (Continued).

Subsection and Detailed Subsection[1]	Code	Within Noatak National Preserve: Number of Polygons	Area (ha)	Area (ac)	Area (%)	Total in Northwest Area: Area (ha)	Area (ac)
Middle Noatak Uplands	MNU	6	54348	134292	2.0	54348	134292
Misheguk Mountains	MIM	2	66058	163228	2.5	66058	163228
Nakolik Mountains	NAM	1	29834	73720	1.1	40593	100303
Natmotirak Foothills	NTH	3	64804	160129	2.4	67834	167615
Natmotirak Mountains	NTM	3	39697	98091	1.5	49630	122634
Nigu Glaciated Uplands	NGU	1	15326	37870	0.6	19028	47019
Nimiuktuk Hills	NIH	2	29155	72042	1.1	29155	72042
Noatak Basin Floodplains*	NBF	9	22815	56374	0.9	22815	56374
Noatak Delta	NOD	1	128	316	0.0	20888	51613
Noatak Glaciated Lowlands	NGL	4	65471	161776	2.5	69193	170972
Noatak Lowland Floodplains*	NLF	7	7676	18966	0.3	13285	32826
Northern Baird Floodplains*	NOBF	10	15761	38946	0.6	16150	39906
Nuka Mountains	NUM	2	46671	115323	1.8	102446	253142
Nukatpiat Hills	NPH	1	13936	34435	0.5	37969	93820
Nukatpiat Mountains	NPM	1	25930	64073	1.0	45247	111805
Omar Foothills	OMH	0	0	0	0	58141	143663
Shiliak Hills	SHH	2	17189	42473	0.6	22493	55580
Shiliak Mountains	SHM	1	8908	22012	0.3	19100	47195
Siniktanneyak Mountain	SNM	1	20635	50988	0.8	21214	52419
Sivukat Mountains	SIM	2	6808	16822	0.3	37801	93404
Skajit Mountains	SKM	1	7911	19547	0.3	10102	24961
Southern Baird Floodplains*	SOBF	0	0	0	0	16453	40656
Squirrel Floodplains*	SQF	0	0	0	0	19968	49340
Squirrel Foothills	SQH	0	0	0	0	49089	121298
Squirrel Lowland	SQL	0	0	0	0	37977	93839
Squirrel Mountains	SQM	11	25404	62773	1.0	132968	328559
Tukpahlearik Mountains	TKM1	1	1669	4124	0.1	49942	123405
Tututalak Mountains	TUM	1	168049	415244	6.3	168306	415879
Upper Noatak Basin	UNB	6	247275	611007	9.3	247646	611924
Upper Noatak Floodplain	UNF	1	28417	70219	1.1	32012	79101
Utukok Mountains	UTM	0	0	0	0	34462	85154
Wulik Foothills	WUH	0	0	0	0	26936	66559
Wulik Mountains	WUM	0	0	0	0	57755	142712
Total		215	2658235	6568413	100	4220442	10428568

[1] Detailed subsections differentiate floodplains within a subsection, these were grouped with the adjacent subsection at the subsection level.